DTIC.

IMPACTS OF WOODY DEBRIS ON FLUVIAL PROCESSES AND CHANNEL MORPHOLOGY IN STABLE AND UNSTABLE STREAMS

CONTRACT MODIFICATION FOR THE USE OF GEOGRAPHICAL INFORMATION SYSTEMS AS A TOOL FOR MANAGEMENT OF WOODY DEBRIS IN DEC WATERSHEDS

by

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PREFACE

The Wallerstein and Thorne computer based woody debris management support system relies on the input of data from files developed through direct field observations coupled to measurements from maps and air photographs. However, the application of GIS technology offers the possibility of automating data file creation for the management program, through the generation of graphical layers within the GIS : namely, topological, river network, sediment distribution, road network and vegetation overlay.

A demonstration ARC INFO based GIS for the Abiaca Creek watershed has therefore been developed, under a modification of contract # N68171-95-C9046, to provide the necessary information, at any point in the catchment study area, for data input into the debris management support system.

The incorporation of the GIS element has been performed by Mr P. R. Cheesman during an intensive four month period between May and August 1995. Mr. Cheesman is a MSc student studying in the Department of Geography at the University of Nottingham for a masters in GIS.

Abstract

This project is based on the work of the Demonstration Erosion Control Project carried out by the U.S.Army Corps of Engineers in the Mississippi regions of the United States. The project demonstrates how a GIS (ARC/INFO) can be used in conjunction with external programming to assist in management practices associated with erosion control. The GIS is used to calculate variables of soil type, land use, and sub-watershed area which are the input variables into a C++ management program, for selected sections of streams in the Abiaca Watershed, Mississippi. The operation of the project is set up so as to facilitate interactive selection of stream sections anywhere within the watershed. The soil type and land use variables are calculated by combining polygon coverages and overlaying them with a stream network. The watershed areas are calculated through the use of a Digital Elevation Model, which was also used to derive the stream network. The C++ management program predicts the likelihood of floating debris build up at any selected section on a particular stream. The system macro language (AML) of the GIS is used to automate the various analysis techniques used in this project. A pull down type menu interface is used to create an interactive user environment which is simple to use and guides the user through the steps necessary to obtain management help. The project is a pilot to establish whether a GIS is suitable for such a task.

Preface

This project was written to compliment the ongoing research of Nick Wallerstein and Prof. C.Thorne on behalf of the U.S.Army Corps of Engineers, Vicksburg District, Mississippi, USA.

I wish to acknowledge with appreciation the assistance and direction of Mr N.Wallerstein and Dr G.Preistnall, and Patricia Peralta; Nottingham University: Brenda Martin, Mr M.Graves and Mr S.Bourne, U.S.Army Corps of Engineers, Vicksburg District, Mississippi, USA, and the U.S.Army Corps of Engineers in general for making the funds available to carryout the research. Finally to my fa~~r~~ther Peter, for his valued constructive criticism and proof reading.

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Conversion Factors, Non-SI to SI Units of Measurements.

Non-SI units of measurement used in this project can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.856	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimetres
miles (US. statute)	1.609344	kilometres
square miles	2.589988	square kilometres

1. Introduction.

1.1 : Context of Study

In the United States of America the U.S.Army Corps of Engineers is responsible for maintaining the coastal and inland waterways that form the backbone of waterbourne commerce in the United States. They are also responsible for the development of hydrological engineering practices which assist in the management of water quality, erosion, flood control, and the predictions of localised management strategies. As part of these ongoing practices, in 1982, the Demonstration Erosion Control Project was initialised to provide for the development of a system for control of sediment, erosion, and flooding in the foothills area of the Yazoo Basin, Mississippi, USA.

Through comprehensive research and ongoing monitoring programs it has been established that organic debris jams or "dams" made up of trees, branches and leaf litter have a significant impact on channel morphology in the Yazoo Basin. This impact is of a financial concern to government agencies due to the risks of bridge failures (see plate 1) and the subsequent possibility of insurance claims due to personal injury, and to farmers because of the excessive land erosion which is occurring constantly in these highly erodible channel regions.

These erosion events have created the need for management action and strategies to combat these ongoing problems. Such management strategies for example, could be the removal of all jams and potential jam material or perhaps just the removal of accumulations around hydrologic structures such as grade controls and bridges. The

problem of implementing such strategies is that it would be extremely difficult indeed to provide such practices over the entire basin; the manpower needed to monitor all these creeks and then carry out any appropriate action would be huge and uneconomical. This has therefore necessitated the need for hydrological predictive models to identify potentially vulnerable areas. Wallerstein and Thorne (1994) have identified some key factors in predicting the effect and likelihood of debris jams, and have subsequently devised a Debris Management Support Program (DMSP) written in C++ programming language to aid in the identification of any vulnerable areas and suggest what sort of management action should take place.

There are increasing requirements for predictive models of distributed hydrological processes which form the basis for further predictions of water quality, erosion, or the effects of different localised management strategies (Quinn et al 1992). Geographical Information Systems (GIS) are becoming increasingly applied to hydrological engineering problems due to their ability to link land cover data to topographical data and other information concerning processes and properties related to geographic location. When applied to hydrologic systems, non-topographic data can include descriptions of soil, land use, ground cover, ground water conditions, as well as man-made systems and there characteristics on or below the land surface. The inherent ability of GIS to link multi layered topographic information in one database and provide the tools for various hydrologically related analyses was seen as the ideal support system to the Management Program derived by Wallerstein and Thorne. The DMSP requires certain variables for input to be able to achieve its management suggestions, namely soil type, land use, and

stream width. The GIS was to be used as the tool to establish these required variables for input into the program.

There is an increasing demand in today's scientific market place, because of increasing financial restrictions, for simpler techniques to assist with what could be considered day-to-day management practices. Moore et al (1992) have recognised that action agencies responsible for land and water management in many parts of the world are being required to identify those areas of land susceptible to various types of environmental hazard and degradation such as the erosion problems occurring in the Yazoo Basin. Therefore, further to the analytical provisions of the GIS it was proposed to establish the system as a simple user friendly interactive management tool which could be quickly applied to any specific stream section in the watershed and consequently provide management assistance, and in addition could be operated by persons which do not necessarily have specific GIS training.

The project utilises a number of data layers representing soil, land use, and road coverages and uses a digital elevation model to establish hydrological characteristics such as stream network and watershed area. Once the necessary functionality of the project requirements had been established the aim was to tie the analytical methods into a menu driven interface which would provide the necessary steps to obtain the required program variables, and then to activate the external C++ program. The output from the DMSP was then to be displayed within the framework of the GIS. User input was to be kept to a minimum as the processing speed was to be considered an important factor in assessing whether the developed system was a viable approach to this task set out. It should be made

clear that this is a pilot project which if considered successful would warrant further development in conjunction with the expected improvements to Wallersteins and Thornes DMSP

This project demonstrates how the use of a GIS package developed by the Environmental Systems Research Institute and referred to as ARC/INFO can be used in estimating the parameters required by the DMSP, and how through the use of its in-system macro language the GIS can be utilised as a simple management support platform which can be interactively used. The data used for this project was already existing data provided by the U.S.Army Corps of Engineers. This paper will review in detail the work of Wallerstein and Thorne and then examine some recent studies in GIS and terrain modelling which are considered relevant to this study. It will then lead onto the methods and approach taken to accomplish this proposed task before presenting the results and discussing its relative merits and disadvantages, as well as establishing whether the developed model is suitable for such an application, and if it would warrant further development.

Bridge collapse tumbles freight train

By Bartholomew Sullivan
The Commercial Appeal

SAVAGE, Miss. — A southbound Illinois Central Railroad train laden with lumber and grain derailed Thursday about 40 miles south of Memphis when a bridge crossing the Coldwater River collapsed, witnesses and a railroad official said.

One witness said the rusty bridge appeared to wobble as cars were crossing it just before 11:45 a.m. The train cracked like a whip as 14 cars plunged through the collapsing bridge into the river.

A small amount of lube oil from one demolished but empty tanker car went into the river, as did spools of paper from the roof of a demolished boxcar and a load of corn from another. Almost a mile away, another seven cars at the front end of the two-mile train were torn from the track, which was badly mangled.

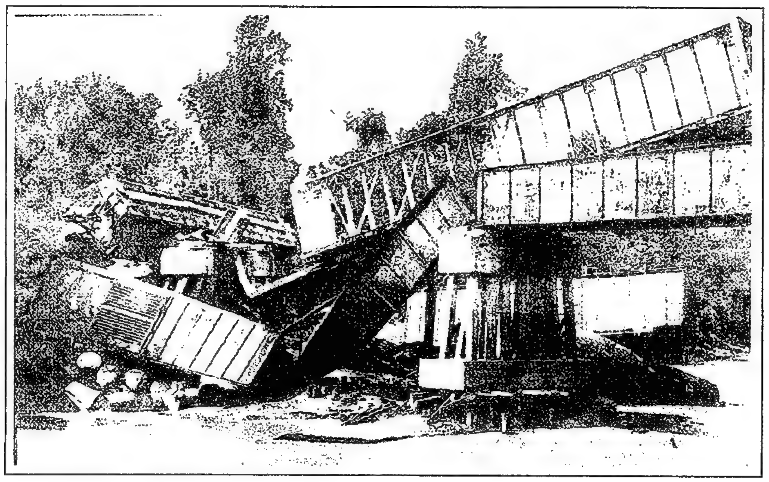
At least one car was separated from its undercarriage by the force of the derailment. Two of the four derailed locomotives spilled diesel fuel, which was being contained by Illinois Central emergency response crews.

Neither member of the two-man crew aboard the 150-car train was injured. Citing policy, Illinois Central spokesman Ann Thoma said their names would not be released.

Dave Ferrari, 42, was walking his dog near the rain-swollen river when the train came over the bridge, which spans the Tunica-Tate County line.

"He came across going slower than they usually do, blew his whistle and all that," Ferrari

Please see BRIDGE, Page A15



A bridge over the Coldwater River at Savage, Miss., about 40 miles south of Memphis, collapsed Thursday morning, sending cars from a freight train into the river. A two-man crew was unhurt and early reports said spillage of oil and diesel fuel was being contained.

MEMPHIS, FRIDAY, MAY 19, 1995 THE COMMERC

From Page A1

Bridge

said. "Then I saw the bridge just giving it this," he said, wobbling his hand in the air. Finally the bridge pilings on the Tunica County side gave way as car after car plunged over the embankment.

"It was just like somebody cracked a rope, and all the cars went up in the air," said Ferrari, pointing to the dented polished-steel wheels on which the cars landed.

Ferrari said he spoke to the engineer to find out if there was any dangerous cargo, and was told there was not. Two tanker cars marked as carrying carbon monoxide had just passed over the bridge before it collapsed and remained upright. Many of the train's cars were empty.

Ferrari, who works for the Sheraton Casino in Tunica, said that because the rural community of about 15 families does not have 911 service, he had trouble reaching the Tate County Sheriff's Department to report the derailment. Ferrari is building a log cabin on a lot that fronts on the river.

Officials from the Tate County Sheriff's Department, Mississippi Highway Patrol, Mississippi Department of Transportation and Illinois Central Railroad were on the scene late Thursday assessing the damage.

Big logs were jammed up against the bridge pilings and Ferrari speculated they could have weakened the bridge supports following recent heavy rains.

John Fitzpatrick, a spokesman for the Federal Railroad Administration in Washington, said inspectors were on their way to report on the cause of the accident. Their preliminary report will be completed within 90 days.

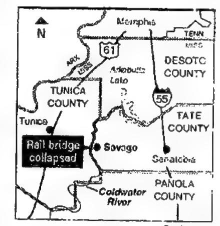
The incident follows a February 1994 head-on collision of two Illinois Central trains near Flora, Miss., in which an engineer was killed. A similar head-on collision in June 1993 derailed 22 Illinois Central cars just north of Greenwood. In that accident, two crew members were injured.

Thoma declined to give the age of the bridge over the Coldwater River but said the entire main line of the Chicago-based freight line is checked twice weekly by inspectors. The entire line was upgraded for safety last year, she said.

"Timber bridges are known to last in excess of 100 years," she said. The bridge involved in Thursday's accident appeared to have a concrete foundation.

The rail line linking Memphis and Jackson has been in operation since the 1870s, Thoma estimated.

The train was on a scheduled route from Memphis to New Orleans via Greenwood, Yazoo City and Jackson. An average of 19 trains use the route each day, according to the Mississippi Department of Transportation's rail division in Jackson.



Staff map

Amtrak, which sends "The City of New Orleans" through Grenada and Jackson, plans to use the more westerly route beginning in the fall. Thoma said those plans have not been affected by the derailment.

But Thoma said the line will be out while the bridge is rebuilt, "so it's going to be out for a while."

Meanwhile, all Illinois Central trains southbound from Memphis will use the alternate Grenada route.

Plate 1: Newspaper Article From A Local Paper The Commercial Appeal May 19, 1995.

1.2 : Literature Review.

The crux of this GIS project is based upon the current research of PHd student Nick Wallerstein at Nottingham University on behalf of the U.S army Corps of Engineers in conjunction with their on-going Demonstration Erosion Control Project. The subject of the research is related to the impact of in-channel organic debris on fluvial process and channel morphology, in the Yazoo basin, Mississippi. The following section will review this research and other material relevant to this GIS application.

The Demonstration Erosion Control (DEC) Project is a multi-year, multi-agency effort designed to provide for the development of a system to control sediment yield, erosion, and flooding in the foothills area of the Yazoo Basin, Mississippi (fig.1). Fifteen watersheds make up the composition of the DEC project. The participating agencies are the Department of Defence U.S Army Corps of Engineers Vicksburge District; the U.S Department of Agriculture Soil Conservation Service and Agricultural Research Service; and the U.S Department of the Interior U.S Geological Survey (USGS).

Wallerstein and Thorne (1994) study assessed the impact of in-channel organic debris jams or 'dams' built up from trees, branches and leaf litter on changes in channel morphology. The primary aim was to determine how organic jams affect water flow and sediment transport and to assess the significance of these effects in causing changes in channel evolution, embodied by width and depth adjustments. These contributors may proliferate the already considerable channel degradation problems in the Yazoo basin.

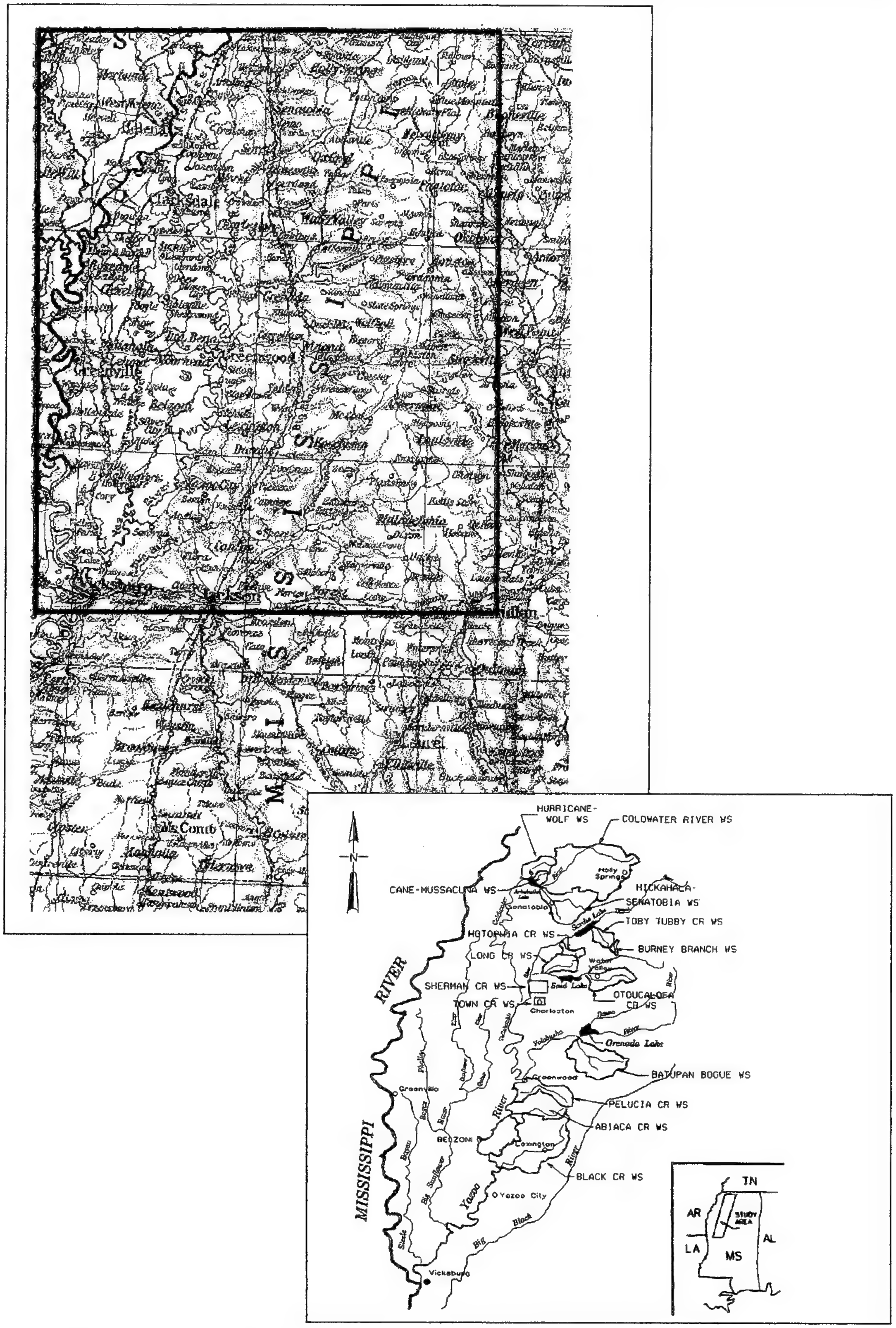


Figure 1 Vicinity Map Of DEC Project Watersheds.

(from DEC Project Fiscal Year 1993 Report)

A working hypothesis was set up to be tested which was: "Debris jams in degrading bluff-line creaks, in northern Mississippi, have on the whole a morphologically significant destabilising impact upon channel morphology, enough so to warrant remedial action.

Through Wallensteins and Thornes review of relevant literature a number of significant variables were identified that influence the impact of debris jams in a river channel, which were;

a. Channel stream power characteristics.

b. Sediment movement and storage relationships.

c. Channel stability.

d. Size and character of river channel in relation to debris size.

e. Spacing and frequency of jams.

f. Size and character of jams and orientation of component material.

g. Age and stability of component material.

From this they state that the morphological impact of debris jams depends upon essentially two main factors 1. the debris jam 2. the inherent climatological and geomorphological characteristics of the drainage basin and channel. It was identified that the characteristics of the creeks in the drainage basins of northern Mississippi exhibit easily erodible, fine-grained bed/rock materials, a flashy flow regime, and channels that are degrading through headward erosion. Through these reasons they chose to investigate specific impacts that debris jams might have upon channel morphology; in particular debris jam formation through wind flow, washout and most importantly as a result of channel bank

collapse following bed degradation which can lead to either exacerbated instability or promote threatening scour at bridge piers.

The field study was approached at three scales;

1. Catchment scale: Through the analysis of aerial videos and large scale maps, to determine whether there was a significant spatial distribution of jams along the length of the creeks and to obtain an overall view of the potential in-channel width and planform adjustments associated with debris jams.

2. Reach scale: Analysis of geomorphological characteristics of the channel upstream, downstream and at debris jams, in comparison with debris free reaches, to determine reach scale and local morphological impacts.

3. Hydro-dynamics scale: Through the measurements of flow variables in jam and jam-free reaches, to assess the magnitude of flow perturbation caused by the debris.

The subsequent analysis of the results obtained from these methods led them to conclude that:

a. The most significant organic obstructions were associated with severely degrading reaches, especially at or just down stream of knickzones or knickpoints.
b. At a local scale, jams tended to course an increase in channel width and a steepening of bank angles.

c. Complete jams were observed more at sites with small drainage areas while larger basin areas contained more partial jams.

d. Impact of debris jams upon channel width varies according to drainage basin area. Basin areas of $5mi^2$–$20mi^2$ were considered to be the most significant sizes in terms that debris jams are destabilising rather than stabilising.

With the evidence obtained they concluded that their working hypothesis was correct for a range of drainage basin areas between $5mi^2 - 20mi^2$ where debris jams have a significant destabilising impact upon channel morphology. They suggested remedial management strategies may therefore be necessary for these middle-order-range of channels.

Management strategies were contrived with respect to past studies, in particular Gregory and Davis (1992) and Palimiter (Institute of Environmental Sciences 1982).

Gregory and Davis carried out a comprehensive study of coarse woody debris in relation to river channel management. The main recommendations of their research opposed the general pre-1970 consensus that all debris should be cleared from channels, for a more conservative approach concluding that debris removal on the whole was undesirable.

Any effective debris management strategy depends on the underlying aim such as;

1. Improving drainage
2. Flood mitigation
3. Navigation.
4. Enhanced fish migration or
5. Aesthetic improvements.

With respect to these aims debris management must consider;

a. channel stream power characteristics

b. sediment movement and storage relationships

c. channel stability

d. size and character of river channel in relation to debris size

e. spacing and frequency of jams

f. size and character of jam and orientation of component material

g. age and stability of component material.

These management recommendations proposed by Gregory and Davis concluded that a conservative approach to debris removal should be adopted for most areas, but that different strategies are needed according to the characteristics of the particular locality.

George Palmiter (1982) proposed methods contradicted the conservative approach of Gregory and Davis and included practices such as;

1. Removal of log jam material by cutting it to a manageable size.
2. Protection of eroding banks using brush piles and log-jam material, with rope and wire.
3. Removal of sand and gravel using brush pile deflectors.
4. Re-vegetation to stabilise banks and shade out aquatic plants.
5. Removal of potential obstructions such as trees and branches.

Wallerstein and Thorne reason that the Gregory and Davis's conservative approach is too simplistic given the variability of channel bed and bank material erodibity in different environments, and size/orientation/age of debris jams, relative to the channel characteristics.

They favour the Palimeter type techniques because these are more applicable to the middle-order creeks in northern Mississippi, which have potentially severe bank erosion problems, especially where man-made structures of variable agricultural land is threatened. In addition to these Palimeter techniques they further recommend a form of soft-engineering whereby it would be beneficial to plant, or encourage low growing vegetation with dense root networks. but a low biomass, such as willows, adjacent to unstable degrading channels, to help stabilise the banks and reduce the likely-hood of immovable debris-jams forming.

The initial findings made in the surveys and the subsequent management proposals have meant that a 'drainage basin management program' has been developed by Wallerstein and Thorne. The methodology of this program written in C++ programming language is shown in figure 2. The input variables are those which were found to be most significant in terms of jam-channel interaction. The input of these variables provide an output which suggests the form of management procedure necessary for any particular selected reach in question, where managerial decisional assistance is required, such as remove all debris along upstream section, construct rip-rap support or highlight bridges at risk to structural failure due to debris build up. This program has been designed to aid engineers, geomorphologists and planners with the management of woody debris in river channels

throughout the catchment network. The variable values required for input into this management program is where the introduction of a GIS is seen as potentially applicable to the overall management support intended by this package and through its implementation provide a simple tool for day-to-day use.

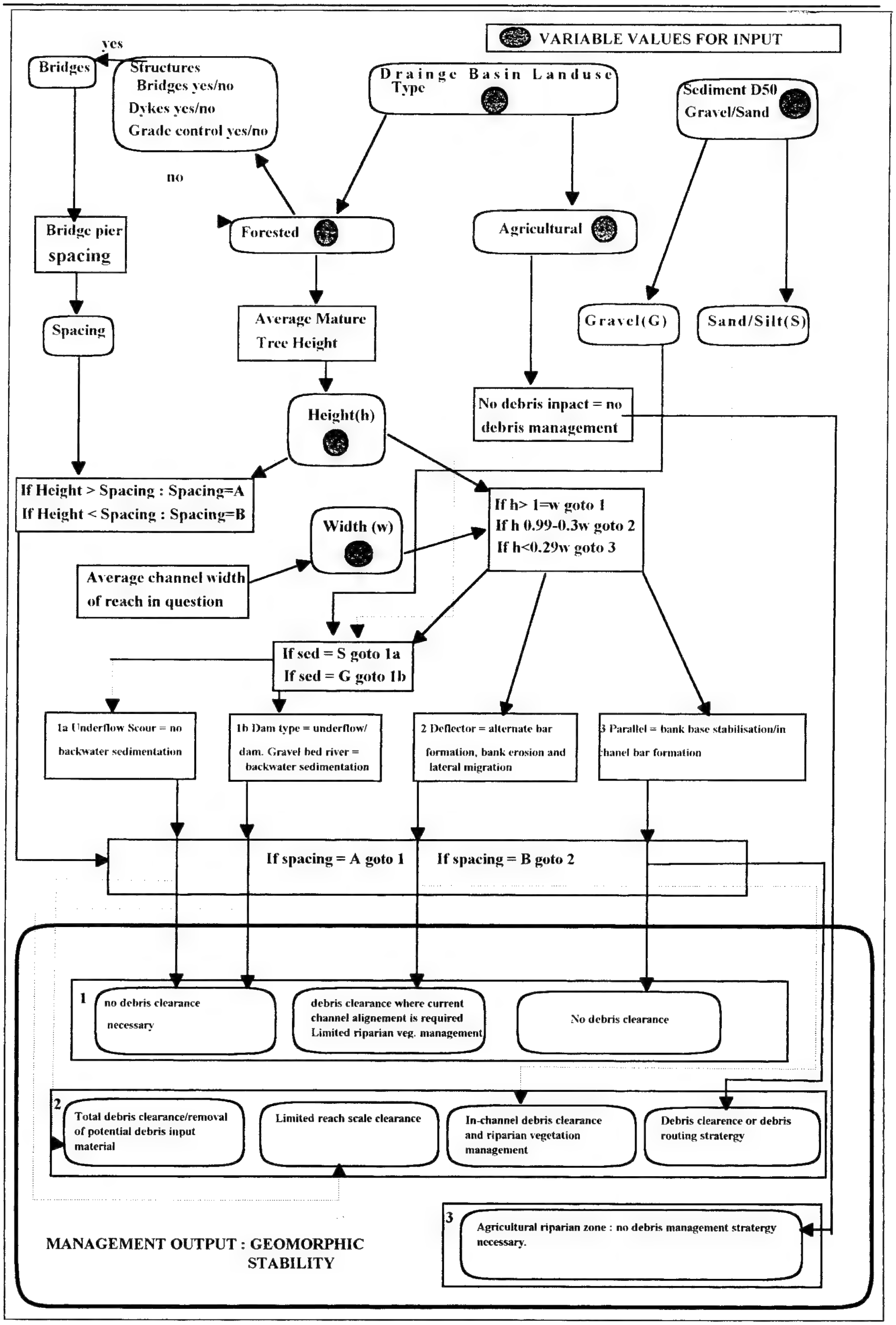


Figure 2: Schematic of Management Program. (from Wallerstein 1994)

Herndon (1987) stated that there was a need for techniques to assist with day-to-day land management practices. Action agencies responsible for land and water management in many parts of the world are being required to identify those areas of land susceptible to various types of environmental hazard and degradation such as erosion, sedimentation, salinization, non-point source pollution, water logging and to assess and manage biological productivity and diversity within landscapes. A number of hydrologically based , topographically derived indices appear to be particularly powerful and useful for determining this susceptibility to hazard (Moore and Nieber 1989). Many GIS and resource inventory systems are being developed storing topographic information as primary data for use in analysing water resource and biological problems (Moore *et al* 1992).

An important data layer in this project is the digital terrain model (DTM) which is used to provide the hydrological input into the model. Djokic and Maidment (1992) highlight how traditionally the methods used to represent terrain for modelling purposes has been obtained using paper topographic and network maps from which information was extracted on watershed area, stream length, watershed slope etc. The advent of GIS technology has automated many of these processes. Djokic and Maidment (1992) used a DTM to calculate watershed boundaries, drainage patterns and flow parameters.

There are three main approaches to computer based terrain representation; rectangular grids, triangulated irregular networks (TIN), and contours (Mark 1979). The

best method depends on the specific use of the terrain model, the available data , and the hardware and software platforms on which the model is developed (Moore *et al* 1991).

For raster grid data structures, Jenson and Trautwein (1987) demonstrate different procedures for depression filling, flow direction determination, flow accumulation, watershed and sub-watershed delineation. Grid algorithms are best applied to large rural watersheds not having abrupt changes in terrain elevation at any location (Djokic and Maidment 1992). They reason that TIN are better suited for areas with abrupt changes in terrain such as constructed surfaces in urban environments. O'Loughlin (1986) and Moore et al (1988) show applications for contour based terrain models for determination of terrain attributes and its use for prediction of surface saturation zones, distribution of potential daily solar radiation. The advantage of contour maps are that they are the most widespread of terrain information currently available.

The grid data structure is the most widely used because of the ease of computer implementation and computational efficiency (Collins and Moon 1981). Moore et al (1992) outline that there can be several disadvantages associated with the use of grid data including

1. They cannot easily handle abrupt changes in elevation.
2. The size of the grid mesh effects the computational efficiency.
3. The computed up slope paths used hydrological analysis tend to zig-zag and are therefore somewhat unrealistic.
4. Precision is lacking in the definition of specific catchment areas.

Quinn et al (1992) state that the increasing requirements for predictive models of distributed hydrological processes, are often to be the basis for further predictions of water quality, erosion, or the effects of different localised management stratergies. They reason that such predictions require that the distributed process be represented accurately which, for any particular catchment area, will depend upon the details of the model structure being used and also the way in which the catchment characteristics are defined. They highlight that a critical catchment characteristic is topography, which will generally have a major control over flow pathways for surface flow and near surface flow processes. In their conclusions regarding the use of DTM's they emphasise that great care and understanding of flow processes are necessary if digital terrain data are to be utilised properly in hydrological modelling. They examined three problems associated with the use of digital terrain data; sensitivity to flow pathway algorithm, sensitivity to DEM grid scale, and the divergence of subsurface flow pathways from those indicated by the surface topography. It was shown that grid resolutions must reflect those features that are vital to the hydrological response, sometimes a finer scale than the 50m scale commonly available. Both routing algorithm and the flow pathway algorithm may have an important effect on the model predictions and, in particular, the pattern of predictions in space.

A problem with the analysis of digital elevation data for hydrological applications is the definition of the drainage paths when the DEM contains depressions or flat areas. Some depressions can be data errors while others are natural features or excavations (Hutchinson 1992). The significance of these depressions depends on the type of landscape represented by the DEM. In landscapes with natural depressions, the numerical filling of depressions in the DEM is used as a method of determining storage volumes and to assign

flow directions that approximate those occurring in the natural landscape once the depressions are filled by rainfall or runoff (Moore and Larson 1979).

O'Callaghan and Mark (1984) proposed algorithms to produce depressionless DEM's from regularly spaced grid elevation data. If the depressions are hydrologically significant then their volume can be calculated. Hutchinson (1989) produced an algorithm which included an automatic enforcement calculation that removes spurious sinks or pits.

Depending on the scale, drainage basins, catchments or subcatchments are the fundamental unit for the management of land and water resources. Many distributed parameter hydrological models, such as the Stanford Watershed Model -SWM (Crawford and Linsley 1966) and the Finite Element Storm Hydrograph Model - FESHM (Ross et al 1979) use the portioning of catchments or landunits each having a single soil mapping unit and landuse type, as a means of crudely representing spatially varying catchment characteristics within the structures of the models (Moore et al 1992).

Estimation of both drainage area and specific catchment area are dependant upon the estimation of flow directions) from a given point (Moore et al 1993). The most commonly used algorithm for determining drainage or contributing areas and stream networks was produced by O'Callaghan and Mark (1984). After producing a depressionless DEM they use the resulting drainage direction matrix and weight matrix to iteratively determine a drainage accumulation matrix that represents the sum of all the weights of all the elements draining to that element. The element weights range from 0.0 (no run-off) to 1.0 (entire element contributes to the run-off) and the drainage direction of each individual

element is the flow direction from the element to one of its eight nearest neighbours based on the direction of steepest descent. If all weights equal one, then the drainage accumulation matrix gives the total contributing area, in number of elements, for each element in the matrix. Streams are then defined for all elements with an accumulated drainage area, above some specific threshold. This method is employed by the ARC/INFO GIS Hydrological Modelling Module. An advantage of the derived information from such methods over manually delineated information is that it is precisely registered to the DEM, allowing more confidence in the localised accuracy of elevation data used to calculate other hydrological parameters (Jenson 1992), this aspect is of fundamental importance to the interactive success of this project as will become clear latter.

An important part of this project, as is with many other GIS applications, is built around layers of data which can be processed to extract the relevant required information. Bhaskar et al (1992) used a GIS (ARC/INFO) to estimate hydrological parameters from selected watersheds within the Big Sandy River Basin in northern Kentucky. Their GIS database consisted of stream network, basin boundaries, soils and landuse coverages. These coverages were individually digitised from USGS quadrangle maps. In conjunction with point rainfall and runoff past records they attempted to simulate these two parameters within the GIS and calculate the geomorphic characteristics of the watersheds. A number of these characteristics were noted to be automatically computed by the GIS software such as individual stream lengths and orders, watershed areas, and perimeters. Through the use of the TABLES module in ARC/INFO they calculated the physical characteristics of the watershed such as basin shape, number of channels of a given order, channel frequency, drainage density and main channel length. All of the geomorphic data for a given coverage

were stored in INFO files. These geomorphic characteristics were computed using the hydrological algorithms already mentioned. They stated that the watershed physical parameters calculated through the GIS were in good agreement with those published in the USGS publications. Using these data conceptualising the watersheds the information was used to generate the geomorphological instantaneous unit hydrographs (GIUH) using the watershed hydrology simulation model (WAHS) developed by Singh and Aminan (1985). Their conclusions were that a GIS can be successfully used to derive all geomorphic information needed to run a geomorphical model such those previously mentioned for hydrological modelling, even as a discrete model. Also concluded was that an interface developed between the GIS and any physically based simulation model would go a long way to simplifying such tasks, and that the successful use of GIS in modelling studies will rely heavily on the development of macros to interface existing modelling software with a GIS such as ARC/INFO.

Priestnall and Downs (1994) demonstrated the use of GIS with vector and Raster capabilities with the addition of 'C' programming language and a user interphase to aid a catchment scale study of river channel adjustments. They concluded that the GIS replaced the need for manual parameter estimation and manual data array production. Commenting on the dual data type capabilities of the GIS they say that data of many forms and of many scales can be incorporated within a GIS database. Their GIS model also provides a framework from which interactive querying of the river and catchment can be undertaken.

Eli et al (1980) applied GIS methodology to predict erosion to surface mined lands. They used the universal soil loss equation (USLE) to predict this erosion. The USLE

requires parameters concerning soil, land-cover, rainfall intensity and topographic parameters. DeVantier and Feldman (1993) state that it is indicative of the simplicity of determination of such parameters for USLE from GIS data that there are very few citations of its use in open literature and it should be realised that erosion potential predictions are a practical and widely applied GIS operation.

2.Methodology.

2.1 : Approach

The preceding review of the literature has shown that the GIS analysis techniques and particularly those associated with hydrologic modelling from DEM's are highly applicable for the input of the variables required by the Debris Management Support Program (DMSP). These variables were previously calculated and input manually through the use of maps and field notes. A fundamental requirement of this project was to extract these variables automatically with limited user interaction and then run the DMSP, all within the framework of the GIS.

Figure 3 outlines the method of approach from variable extraction to the final output from the DMSP.

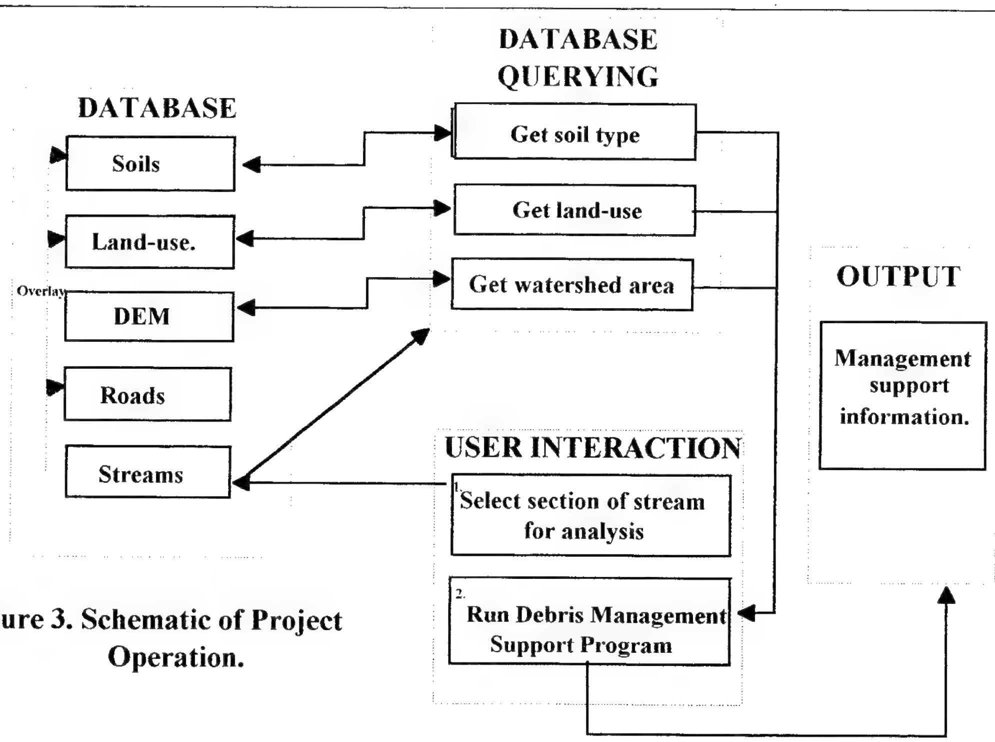


Figure 3. Schematic of Project Operation.

The section of stream which the user is querying is interactively selected by using the screen cursor operated by the mouse. This will provide the coordinates for the analysis from other data layers which are all geometrically aligned. ARC/INFO provides interactive selection facilities which enable the user to select points on the display screen. The stream network coverage will contain attribute information detailing the soil types and landuse for each arc section of stream. The original stream coverage data contained no attribute information relevant to the study. A function command called IDENTITY enables arcs (lines) to be overlaid onto polygon coverages and relate the attributes from the polygon coverage to the arcs coverage, where the arcs overlay and intersect the polygons. By converting the grid layers, soil types and landuse to polygon coverages this IDENTITY command is then used to attach the attribute information from these two data layers to the stream network. ARC/INFO facilitates conversions from raster to vector, and the GRIDPOLY command was used to convert the two raster files. Then using the IDENTITY command the stream network can be overlain onto the soil polygon coverage, then the resulting new stream network coverage with soil attributes can be overlain onto the landuse polygon coverage resulting in a stream coverage which has attached soil type and landuse attributes. The methodology of this process is summarised in figure 4.

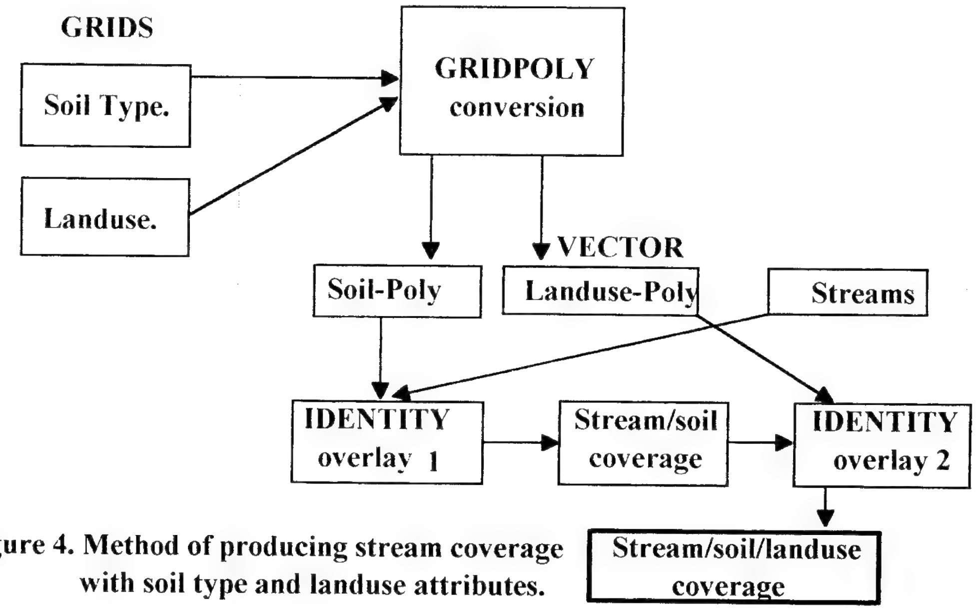


Figure 4. Method of producing stream coverage with soil type and landuse attributes.

An important requirement for the success of this project is that the stream network is geometrically true to the elevation grid for the calculation of the watershed area upstream of the query point. The interaction with the stream network is the sole method of producing a coordinate reference point, which is used as the starting point or watershed pour point for the area calculation from the DEM. It was therefore decided that the likelihood of every section of the original vector scanned stream coverage being a precise match to the DEM was unlikely. If it didn't match precisely it would cause the failure of the analysis method because the watershed area that would be calculated would be incorrect. For this reason the stream network was produced from the DEM, and converted to a vector coverage through the command GRIDLINE, and then the same procedure of producing a stream coverage with soil and landuse attributes was carried out.

2.2 : The Digital Terrain Model.

A common problem in using DEM matrices for detecting linear features such as stream networks is that of depressions (sinks) in the digital surface caused by noise. The noise may result from short range variations on the digital land surface or as a result of the quantization of the original data. Ridges and drainage courses may be missed because the grid is too coarse. ARC/INFO can detect these sinks and fill them. A sink is defined as a cell whose elevation is less than or equal to that of its eight neighbours when passing a kernel of 3x3 cells over the elevation grid (Marks 1984). ARC/INFO uses Marks method to detect these sinks and by setting a minimum elevation, which in this case was 83ft, these sinks can be filled upto that minimum height. The command FILL was used with the options of SINKS and a z value set at 83. From here the depressionless DEM was used to create matrices necessary for further analyses. The command FLOWDIRECTION creates a flow direction matrix from the DEM, which is achieved by computing the local gradient and aspect for every cell. This flow matrix is used to determine the boundary of the catchment or selected sub-catchment, the method of which is detailed in the literature review page 18. To find the stream network from the DEM a flow accumulation grid needs to be produced. The method behind this is an algorithm which for each cell, compares its altitude with its eight neighbours within a 3x3 kernel. The lowest neighbour is flagged, and the amount of water (which is expressed as a function of the number of cells traversed and the area of the cell) is carried over to that cell. The kernel is moved to the lowest neighbour, and the process is repeated. The ARC command that is used to carry out this process is FLOWACCUMULATION. A stream network can then be delineated using the output from this flowaccumulation grid. Flow accumulation in its simplest form is the number of up slope cells that flow into each cell, therefore by applying a threshold value to

the results of this FLOWACCUMULATION using a grid algebraic expression, a stream network can be defined. An expression was used to create a grid where the value 1 represented a stream network on a background of no data, the expression was:

stream network = con (flowaccumulation > 100, 1)

This assigns the value 1 to all cells with more than 100 cells flowing into them, and all other cells are assigned no data. A final process that was carried out, was to apply Strahler's method of stream ordering achieved through the use of the command ORDER. The reason for creating this grid was to create a visual guide to the user, the network is colour coded, white representing a stream order of 1, while bright pink was a stream order of 6. This visual guide will help in indicating whether a large drainage area is expected.

Once the necessary data had been constructed in the database a set of Arc Macro Language (AML) statements was used to extract the variables necessary for input into the DMSP. A command named RSELECT enables the user to interactively select a point on the stream network displayed on the screen. This function then selects all the attributes associated with that one arc which has been selected. These attributes are stored in a named INFO file (TRY) created by the RSELECT function. The next step is to calculate the upstream watershed area from that selected point. ARC/INFO command WATERSHED allows interactive selection of a pour point from the screen. By selecting at the same point as before (the RESELECT function leaves a small box on the screen marking the previous selection point, the user will select the point again), the WATERSHED function creates a new file which represents the sub-watershed only. The count attribute in the new sub-watershed file represents the number of grid squares which make up the area of the sub-watershed. In the ARC module TABLES, a new item can be

created for this file called area, and then using the CALCULATE function within TABLES assign a data value to it representing the number of squares x 0.00036 (one grid square = 0.00036 miles^2). Two files are therefore created in the analysis, one containing the values representing the soil type and landuse at the selected point on a stream, and one file containing the upstream watershed area from that point.

In TABLES using the function UNLOAD the relevant items from these files can be selected and put into a text file which will list the landuse, watershed area and soil-type respectively. This text file is the input file into the Debris Management Support Program.

At the arc prompt the function TASK activates a program outside the ARC/INFO environment. This TASK command is used to execute the Debris Management Program which imports the text file containing the input variables. The DMSP creates an output text file which details the soil type, landuse and stream width (calculated from the watershed area) and the form of management which should take place at that section of the stream network in the Abiaca Watershed. This program is written in the C++ programming language and is a series of simple IF ELSE type statements relating to the input variables, this program is listed in appendix B.

2.3 : The Menu Driven Interface.

The final part to the method for this project was to tie all the data layers and interactive analyses functions together in a menu driven interface. The type of menu chosen was the pulldown version which is perhaps the most familiar to Personal Computer users. An ARC/INFO menu file is a text file which was created in the operating systems

text editor. The format of the menu determines how the menu is to be displayed and which choices are to be included, and what action is taken when a selection is made. Figure 5 shows the format for this menu file with explanatory text written in red. The AML files are listed in the appendix A.

```
1 Debris Management Support pulldown menu
Draw                 **main menu choice, with sub-menu choices below**
  Landuse              &R LAND       ** runs the AML land (displays landuse)**
  Soils                &R SOILS      ** runs the AML soils (displays soils)**
  Streams              &R STREAMS    ** runs the AML streams (displays streams)**
  Roads                &R ROADS      ** runs the AML roads (displays roads)**
' List Attribute'    **main menu choice, with sub-menu choices below**
      Landuse            LIST AB-LAND-GRID.VAT      **lists attribute file**
      Soils              LIST AB-SOIL-GRID.VAT      **lists attribute file**
      Streams            LIST FINAL-NET.AAT         **lists attribute file**
    'Check Count'        LIST TEST.VAT              **lists attribute file**
    'Soil & Landuse'     LIST TRY                   **lists attribute file**
' Analysis'          **main menu choice, with sub-menu choices below**
     Help                &POPUP ANL-HELP.TXT   **displays help text file**
     Zoom                &R ZOOM.AML           **runs the AML zoom**
   'Calculate Variables' &R del.AML            **runs the AML del**

' Run Program'       **main menu choice, with sub-menu choices below**
      Run                &R FILE.AML           **runs the AML file**

' Clear'             **main menu choice which clears current display**

' Quit'             &RETURN          **quits the menu display**
Quit
```

Figure 5. Pulldown Menu text file.

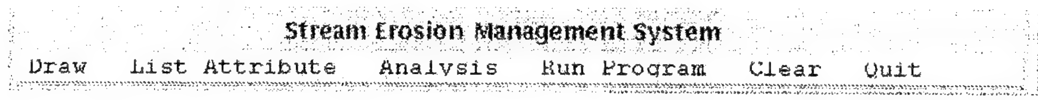


figure 6. The menu title bar.

Figure 6. displays the form the menu takes, the usual method of clicking on a subject with the screen cursor either activates a process or provides further choices.

Draw: provides a list of coverages to be drawn on the screen.

List Attributes: provides a list of coverages from which the attributes associated with them can be chosen.

Analysis: activates the stream analysis section of the project, provides a series of help menus to guide the user through the process.

Run Program: after the stream variables have been collected the DMSP can be activated.

Clear: clear the current display on the screen.

Quit: quits the menu and returns to the arc prompt.

The menu is set up in such a way that choosing a subject activates an AML program. This is set-up so that the user need not be aware of the processing that is taking place when they make a choice, the user need not be proficient in ARC/INFO commands. The AML programs are a list of on line commands which activate various ARC/INFO functions. These AML's could all be accomplished by typing in the numerous commands line by line. Instead an ARC/INFO function &WATCH will record all line entries made until switched off. This creates a watch file which contains all the commands entered at that time, these watch files are then converted to AML through the command CWTA (convert wacth file to AML). By setting up watch files whilst doing the individual process by line entry, such as the commands entered to zoom in on the analysis area (see appendix A.7) separate small command files were created which would carry out a whole process just by activating the particular AML program file in question. These AML files are then brought together through the menu interface. Figure 7 shows a schematic diagram of the outlining operation of the menu interface and how it links with the GIS database

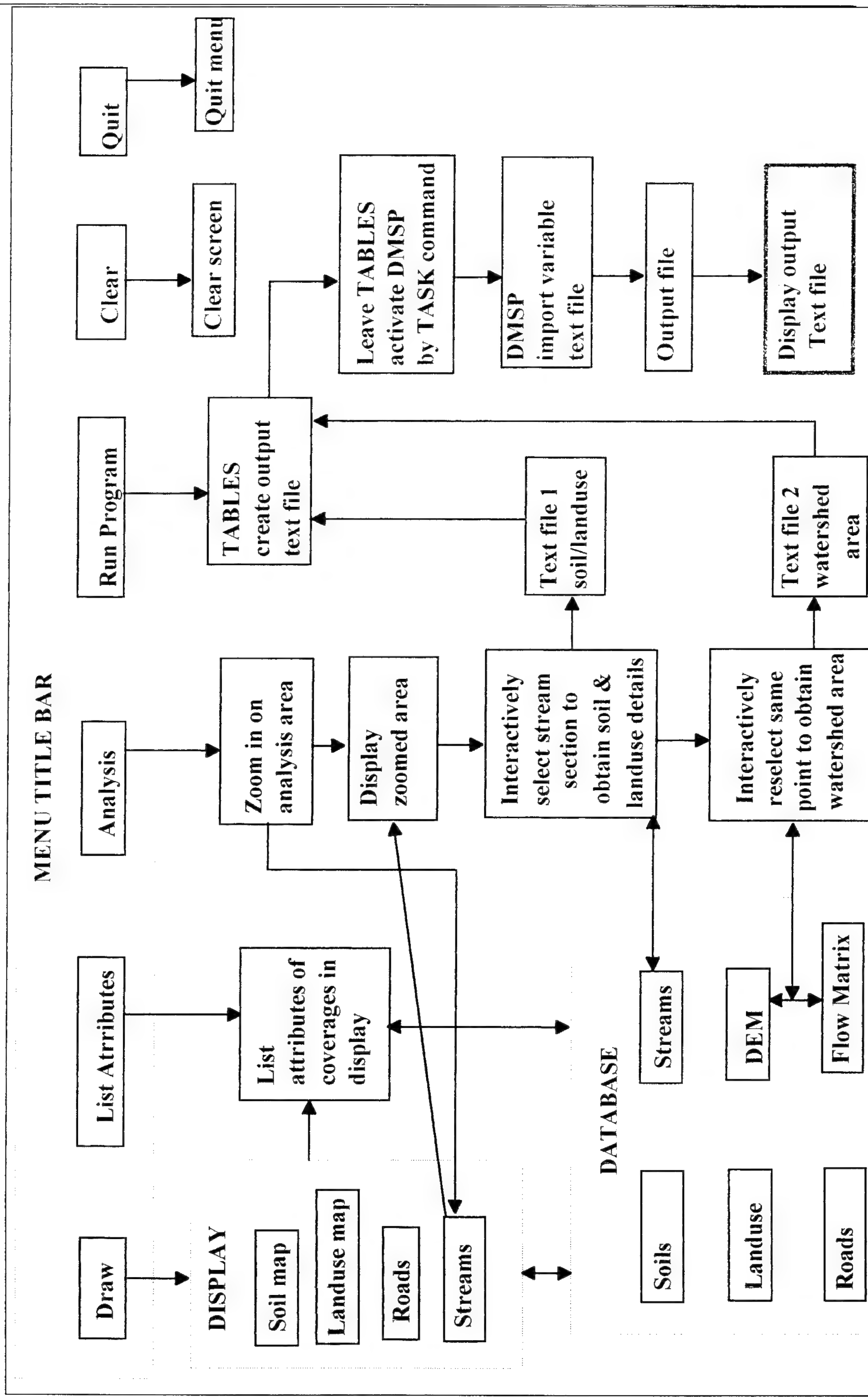


Figure 7. Schematic of menu operation

2.4 : Displays

The soil type and land use images were developed to show a key and title each time the image was selected. This is achieved by generating a map composition and a graphics file The map contains a series of themes that can be combined to form the final product. To create a key legend for the image, a key legend file which is a form of lookup table is created. This file relates the values used in the data cover, which will be displayed as the same colour as that feature, with appropriate descriptive text. Another process which was carried out was to create a more meaningful DEM display. This was created by constructing a shaded relief model based on elevation and afternoon sun. The shading was achieved by classifying the DEM into 33 elevation bands. Each elevation band was assigned a colour based on the hue saturation value (HSV) colour model. Hill-shading values, based on the illumination source in the northwest, were applied to adjust the colour values for each location. The colours ranged from pale green (low elevation) through to red (higher elevation).

2.5 : Summary of Main ARC/INFO Functions Used.

Listed below are some of the key ARC/INFO commands used in the project with brief descriptions of their function.

IDENTITY : computes the geometric intersection of two coverages. All features of the input coverage, as well as those features of the identity coverage that overlap the input coverage, are preserved in the output coverage.

RESELECT :	selects a set of records from the specified object i.e. arc attributes.
SINK :	creates a grid identifying all sinks, or areas of internal drainage.
FILL :	fills sinks to the value of the lowest boundary cell in the watershed.
FLOWACCUMULATION :	creates a grid of accumulated flow to each cell, by accumulating the weight for all cells that flow into each downslope cell.
FLOWDIRECTION :	creates a grid of flow direction from each cell to its steepest downslope neighbour.
WATERSHED :	creates a grid of the upslope area contributing flow to a given location.
STREAMORDER :	creates a grid of streams characterising the stream network based upon their number of tributaries.
HILLSHADE :	creates a shade relief grid from a grid by considering the illumination angle and shadows.
GRIDPOLY :	converts a grid to a polygon coverage. Polygons are built from groups of contiguous cells having the same cell value.

2.6 : Data Source.

The original DEC Project data resides on an Intergraph 6080 workstation, and access to the database is made with Intergraph GIS software. The purpose of the engineering database/GIS is to serve as a repository for all design, analysis, and monitoring data collected on the DEC Project. It is still in a development stage but when completed it is anticipated that the database will contain design data for all project features such as low- and high-drop structures, bank stabilisation structures, floodwater retarding structures, channel improvements, levees, riser pipes, and box culverts. This design data will be complemented with data coverages suitable for various hydrological analyses such as DEM's and soil type data.

The database contains 1:24000 digitally scanned USGS quadrangle maps and DEM's for all of the DEC Project watersheds. All major tributaries and highways, which have been obtained from 1:100000 USGS Digital Line Graph (DLG) files are incorporated into the database in vector format, these maps were again digitally scanned rather than digitised. Spot-view satellite photography has been incorporated into the database and is used as a visual reference for all DEC Project features. Landuse and soil type data for the DEC watersheds are incorporated in the database on a 1-acre grid. Elevation data is present on a 100ft grid.

The data that were made available for this project were the elevation, landuse and soil type grids, which were in Geographical Resource Analysis Support System (GRASS) format, and the stream and road vector files in Interactive Graphic Design Software (IGDS) format. The vector files were visual files only and had no specific attributes attached to

them. The watershed chosen for this study was the Abiaca Creek Watershed which is one of the fifteen watersheds within the DEC Project; its location is shown in figure 1. It was chosen solely because it was one of the smallest of the watersheds, approximately 100 square miles and thus was less data intensive and space monopolising than other larger watersheds. It is logical to think that what was carried out on this watershed would be possible on all of the others.

To import the GRASS files into ARC/INFO, it was a simple case of converting the image (GRASS) file to GRID format by initialising the command IMAGEGRID, which is one of ARC/INFO's raster conversion programs. The IGDS files were translated into ARC/INFO coverages with the IGDSARC command. Before this IGDSARC command was implemented the command IGDSINFO was used which provided a summary of what the IGDS file has in it. IGDS files can be multi-layered coverages and it is therefore necessary to identify the specific layers contained in the file for conversion. IGDSINFO provided a breakdown of the total number of elements, the names of the elements and how many of each, plus a breakdown of level, style, colour, and weight and the number of occurrences for each. The road and the stream networks were all present in one IGDS file, which also contained data on hydrological structures. All the layers and options that were entered during one IGDSARC conversion were converted to the same ARC/INFO coverage. The roads were in separate layers with respect to their class i.e. major or minor. All the layers which represented these roads were entered during one IGDSARC conversion and thus made up one ARC/INFO coverage representing the roads in the Abiaca watershed, shown in figure 8. The same process was carried out to create the stream network, shown in figure 9. Figures 10, 11 and 12 display the soil type, landuse, and DEM respectively.

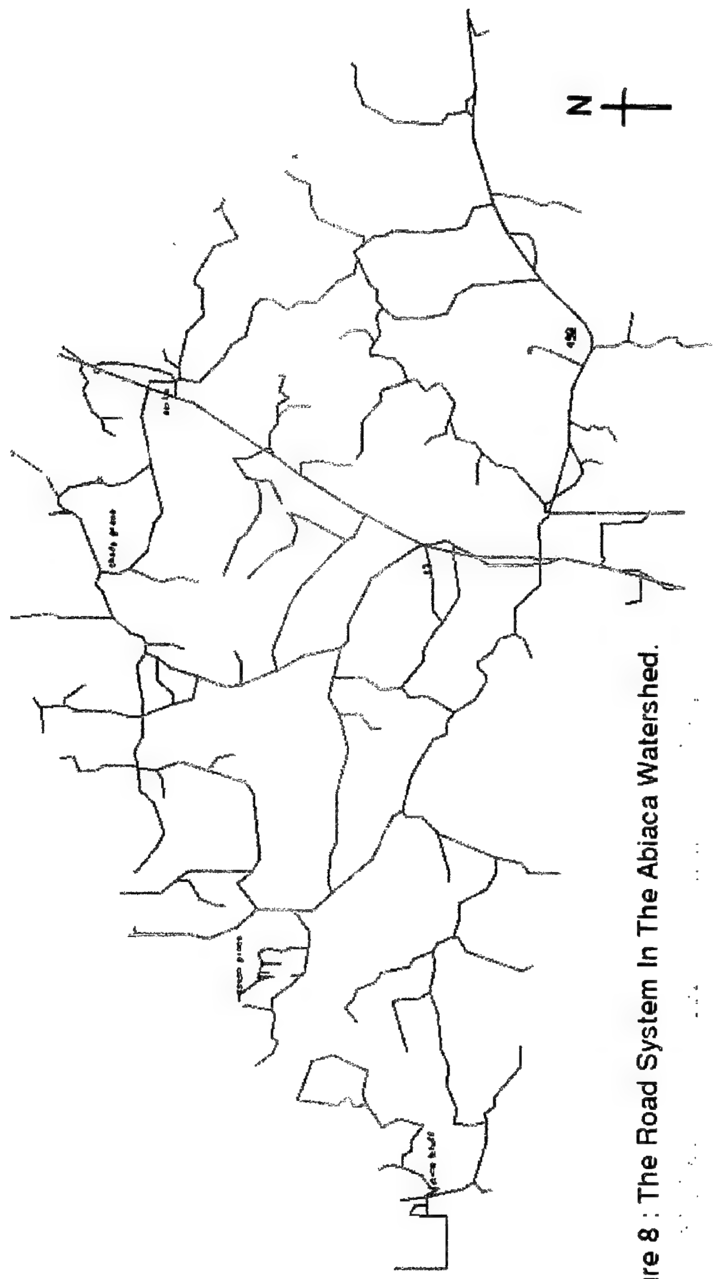


Figure 8 : The Road System In The Abiaca Watershed.

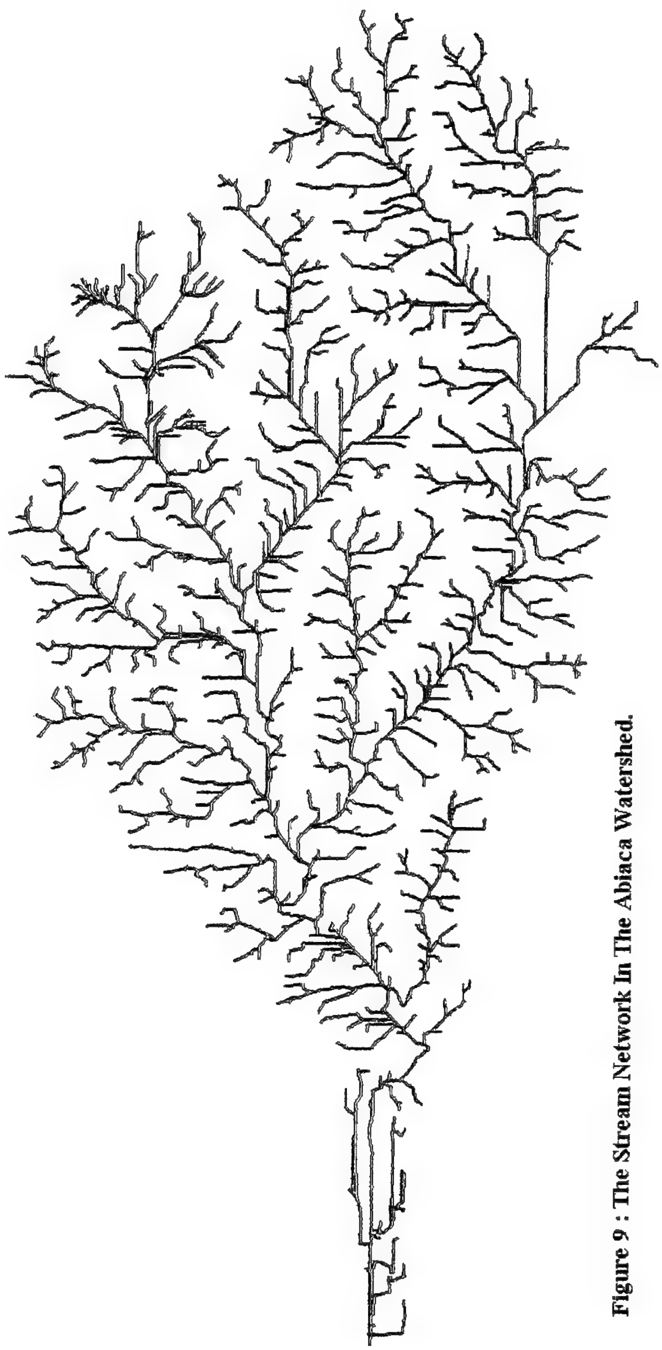


Figure 9 : The Stream Network In The Abiaca Watershed.

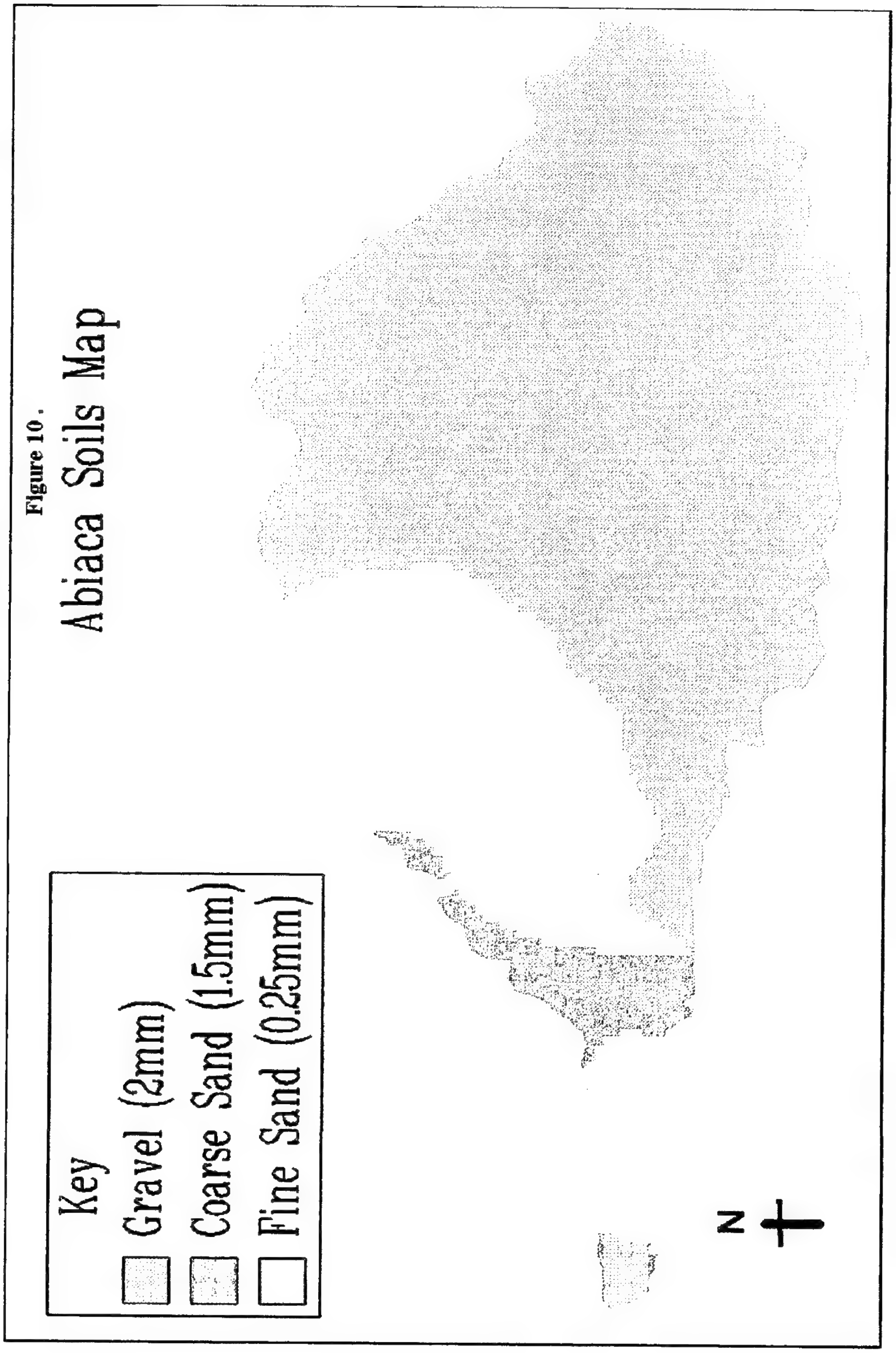

Abiaca Soils Map
Key
Gravel (2mm)
Coarse Sand (1.5mm)
Fine Sand (0.25mm)
N

Figure 10 .

Figure 11.
Abiaca Landuse Map

Figure 12 : Colour Shaded DEM Of The Ablaca Watershed (Lowest In Green (87ft) -> Highest In Red (439ft).

3.Results.

3.1 : Data Layers.

The coverages and grid files for the roads, streams, soil types, landuse, and DEM are shown in figures 8 - 12 respectively.

The roads which are in vector format are literally only a visual guide for indicating where on a stream a bridge occurs (an overlay of the two networks indicates a bridge at any intersection). These are potentially vulnerable areas when the debris build up is indicated causing possible failure of the bridges due to excessive stream bed scour. By carrying out the stream analysis upstream of the intersection point i.e. a bridge, these bridge sites can be analysed.

The stream network (figure 9) has been created from the DEM. It matched with the original digitally scanned vector network in general shape, the main channels being very alike, but as indicated in the literature review the derived network was somewhat more zig-zagy in character. Far more minor tributaries were apparent in the derived network, although the vector network was scanned from a 1:100000 USGS map which would not have picked up these very small tributaries which are apparent in the DEM derived stream network.

The soil type map (figure 10) shows only three types of soil in the watershed. These soil types are classified by their particle size which is the requirement for the Debris Management Support Program. In the top two thirds of the watershed the soil type is of gravel composition with an average particle size of 2mm. Following this zone is a band of

fine sandy soil with particle size 0.25mm, followed by a narrow band of coarser sandy soil, particle size 1.5mm, then again a region of finer sandy soil before finishing with a small area of coarse sandy soil at the outlet of the watershed. To compile the attributable information in the stream network, this grid was converted into a polygon coverage of five polygons.

The landuse map (figure 11) again only shows three types of landuse type in the watershed. The small nose like extension from the main body of the watershed in the western region is almost entirely agricultural land; this is where the watershed reaches the end of the bluff and stretches out into the floodplain. The main body of the watershed is generally forest interspersed by agricultural land and small lakes. The original raster image contained twelve landuse types, forest, lakes and ten differing types of agricultural land. When this original image was converted to a polygon coverage, ARC/INFO was unable to complete the conversion because the polygons created exceeded 10,000 which is ARC/INFO's limit. The raster image was therefore reclassified, all agricultural types were classified as one type. The significant variable value in the DMSP is whether the landuse is forested or not, different types of agricultural land are not distinguished and therefore one value was sufficient. The grid to polygon conversion then created a more manageable number of 1251 polygons.

The DEM shown in figure 12 is colour shaded based on elevation and afternoon sun which enhances the readability of the map. It is very clearly shown where the flood plain gives way to the bluff, where the pale greens change to pale pinks. A marked feature of this map is the apparent visibility of the main drainage channels, beginning from the bluff line

where the Abiaca Creek protrudes out into the flood plain. Very little shadow effect is evident which is due to the fact that the region is in general only slightly undulating with a minimum elevation of 83 feet and a maximum of 439 feet. Figure 13 shows the DEM in a three dimensional perspective with the shaded relief map draped over it. The z values have been exaggerated to emphasise the sudden change from the flat flood plain into the more undulating bluff region.

Figure 14 shows the stream network defined by Strahlers method of stream ordering, streams range from one (grey) to six (pink). As previously mentioned in the method the reason for producing this image of stream orders is to act as visual guide. When the user zooms in on a section of stream for analysis the resulting image that is redisplayed is the colour coded stream order image (figure 16). This colour coding helps the user know which stream is the main channel in this zoomed image, necessary because the zoomed image looses overall visual interpretability.

An important procedure to the success of this project was the results of the IDENTITY overlay of the streams, soil type and landuse coverages. Table 1 shows an example of one of the arc attributes in the final stream coverage. The features which were irrelevant to the analysis such as the polygon attribute details other than the soil and landuse details were edited out of the attribute table.

```
list final-net.aat

arc 1
FNODE#     1
TNODE#     2
RPOLY#     0
LPOLY#     0
LENGTH     876.254
COVER#     1
COVER-ID   1
SOIL-TYPE  Coarse Sand
SOIL-CODE  1.5
LANDUSE    Agricultural
LAND-CODE  1
```

Table 1: Feature attribute table for stream network after overlay with soil type and landuse polygon coverages.

When an arc is selected from the stream network the RESELECT function creates a new file with the attributes such as those in table 1. Then, as detailed in the method, within the module TABLES a text file can be created with only the values selected from the SOIL-CODE and LAND-CODE elements of the attribute table.

The method of finding the watershed area resulted in a file which was as detailed in table 2.

Record	Value	Count
1	1	2279

Table 2. Watershed Area File.

Again within the module TABLES this file is first amended by adding an extra feature to it called Area and then calculating the value for it by multiplying the count value by 0.00036 which creates a value under the new item Area, which is the area in square miles for the watershed just calculated under the analysis (table 3). In this case the area is equal to 0.82 square miles.

Record	Value	Count	Area
1	1	2279	0.82

Table 3. Watershed Area File Updated in TABLES.

The remaining process that occurs whilst in TABLES is to create the output text file for the program. Using the command UNLOAD a text file called dump.txt is created where the attribute items SOIL-CODE, LAND-CODE are selected from the RESELECT file and AREA from the watershed area file. These attribute values are placed in the order of landuse, drainage area and soil type as shown in table 4.

1
0.89
1

Table 4. An Example Of The Input File For The Debris Program.

3.2 : Results Of The Menu Interface.

Figure 15 shows the menu interface displaying first the landuse map with the streams (in blue) and roads (in yellow) overlaid. This was achieved under the DRAW option on the menu title bar. This provides the user with the ability to carry out some visual interpretation such as identifying bridging points before they choose to analyse a specific area. The text box shown in figure 15 is the first thing which appears when the user clicks on the ANALYSIS choice on the menu title bar. It encourages the user to zoom in on the area for analysis, the reason for this is that it is difficult to select an arc at such a small visual scale. When zooming in on an area the user interactively drags out a small box around the chosen section, once the box is defined the screen clears and then redisplays the selected area as shown in figure 16. After zooming in on the chosen section the user then selects the 'analyse streams' choice in the sub menu of the ANALYSIS option. The text box shown in figure 16 explains to the user how to activate the analysis by placing the cross hairs onto the stream section of their choice, once a choice is made a small box indicates where the choice was made, as shown in figure 17. The text box shown in figure 17 explains to the user to re-select the box to activate the watershed calculation. Further text boxes are displayed after this if the selection process has been unsuccessful, i.e. the positioning of the selection point failed to select an arc, or the watershed area was far too low which would indicate that the selection point was not in the grid square of the stream channel on the DEM. Once this process has been completed the user activates the DMSP by selecting RUN PROGRAM on the menu title bar. First this will carry out the processing in TABLES as previously mentioned before activating the DMSP through the TASK function. Once the DMSP has processed the variables a results text box is

automatically displayed on the screen as displayed in figure 18. From this current worked example it can be seen that the land type was agricultural, the drainage area was 99.62 miles square, and the sediment D50 was 2mm. The section chosen for this analysis was close to the watershed outlet and through visual interpretation of figures 7 and 8 it can be seen that the soil and land use types were correct. The published watershed area for Abiaca is approximately 100 miles square which matches favourably with the calculated area for this example. As would be expected for such a reach present in agricultural land the management suggestion is that there is little threat of erosion due to debris build up. Figure 19 shows an example of DMSP output which indicates a steam section in forested land with sediment size of 0.5mm and an watershed area of 43.76 miles square. The management recommendation here indicates that debris jams are a risk and that steps such as debris clearance when seen should be removed and that bridges should be monitored.

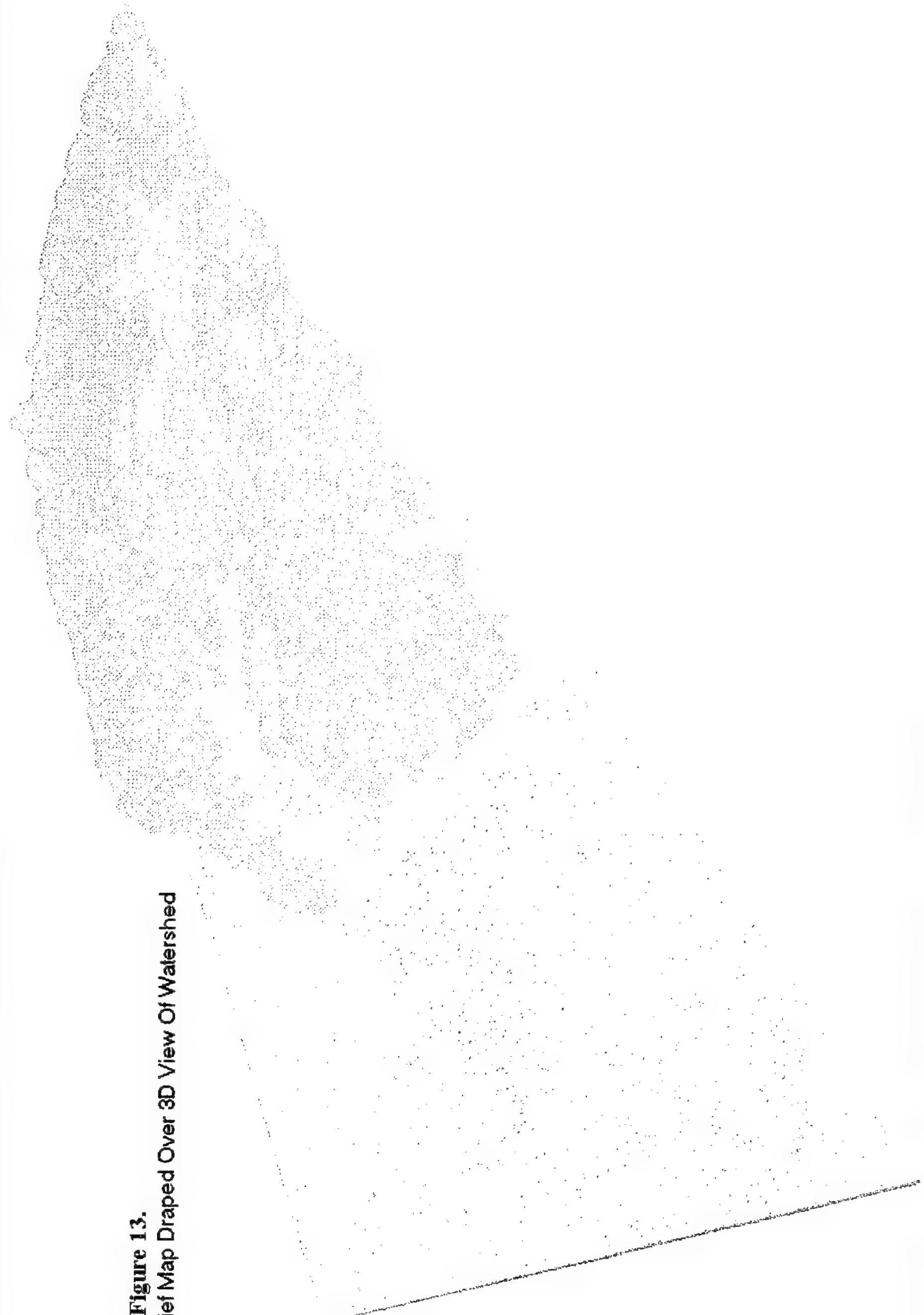


Figure 13.
Relief Map Draped Over 3D View Of Watershed

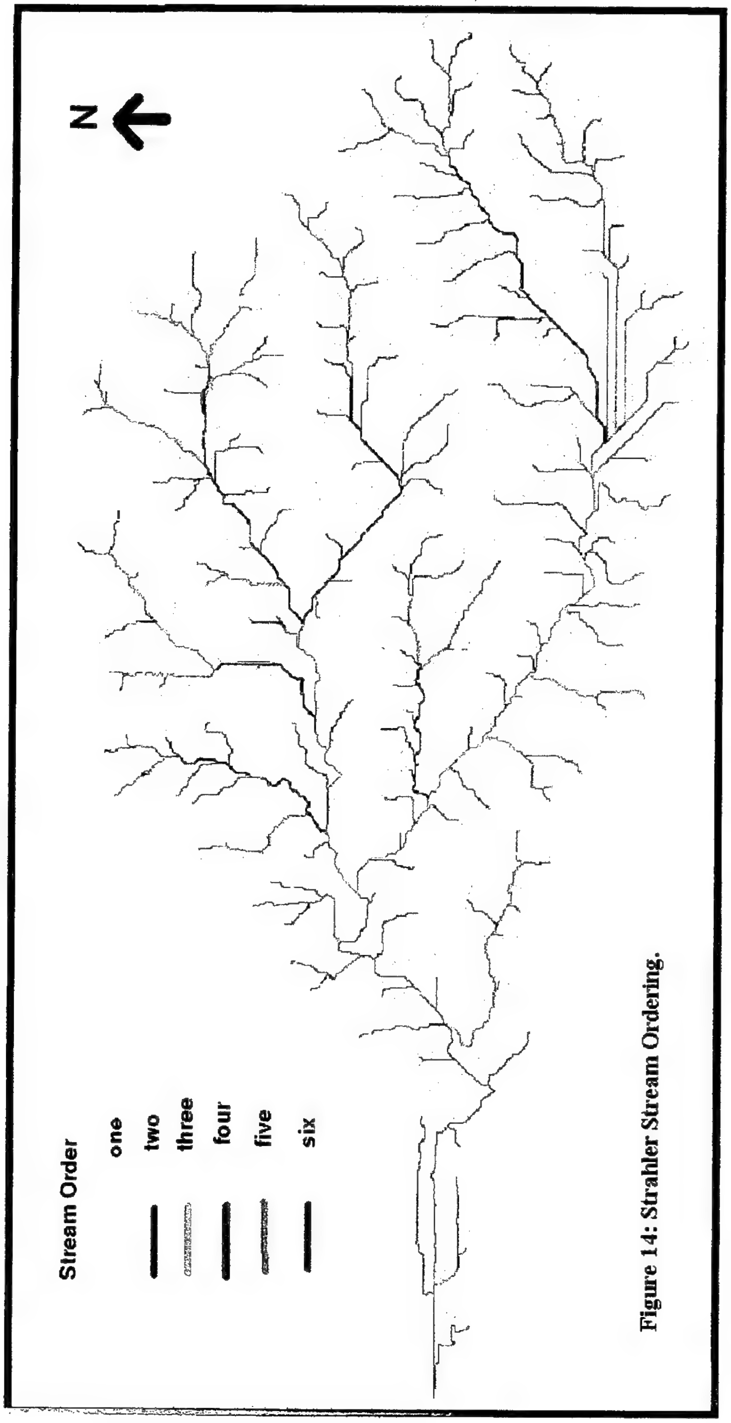


Figure 14: Strahler Stream Ordering.

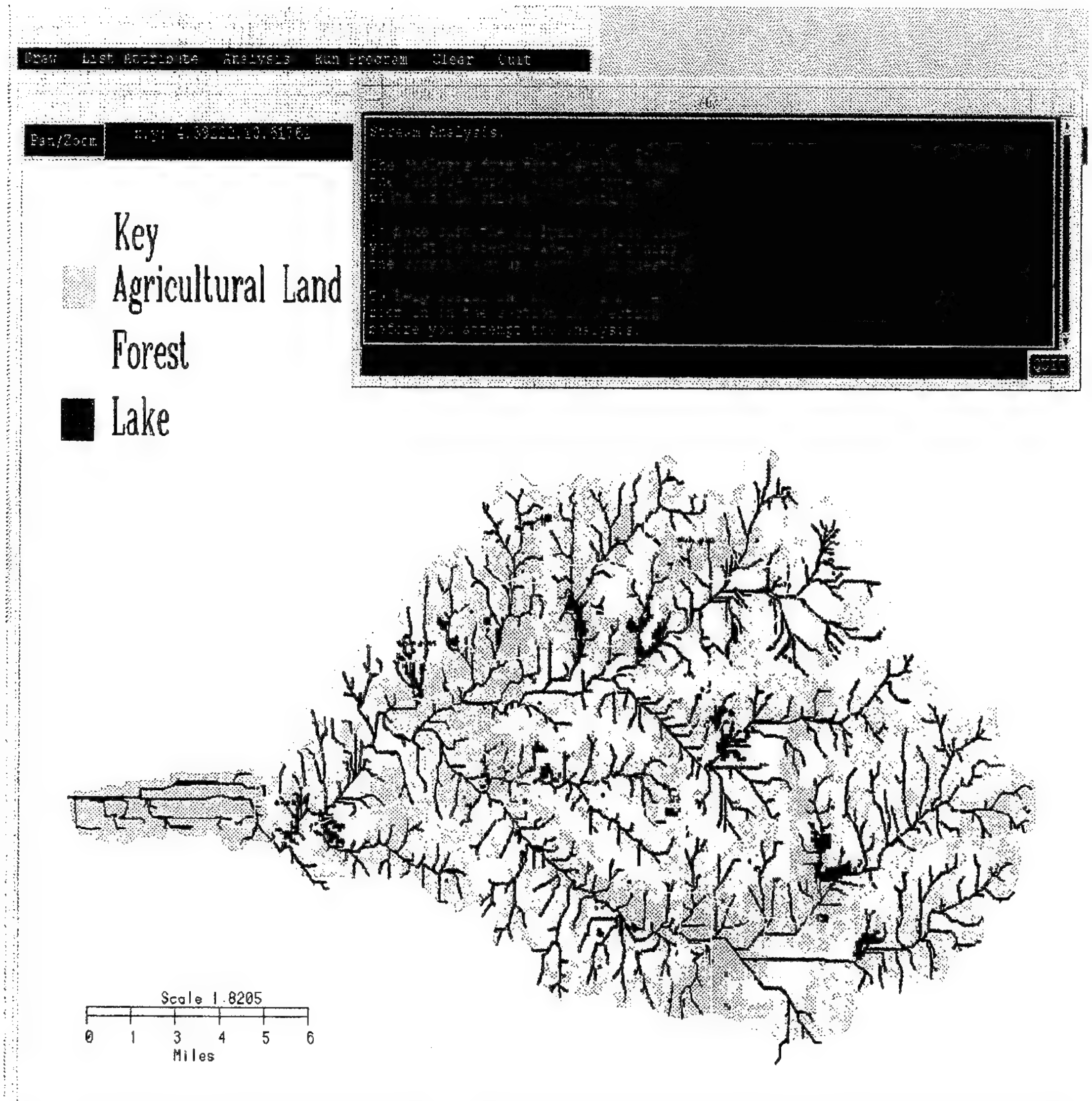


Figure 15: Menu Display Of Land Use With Streams And Roads Overlaid.

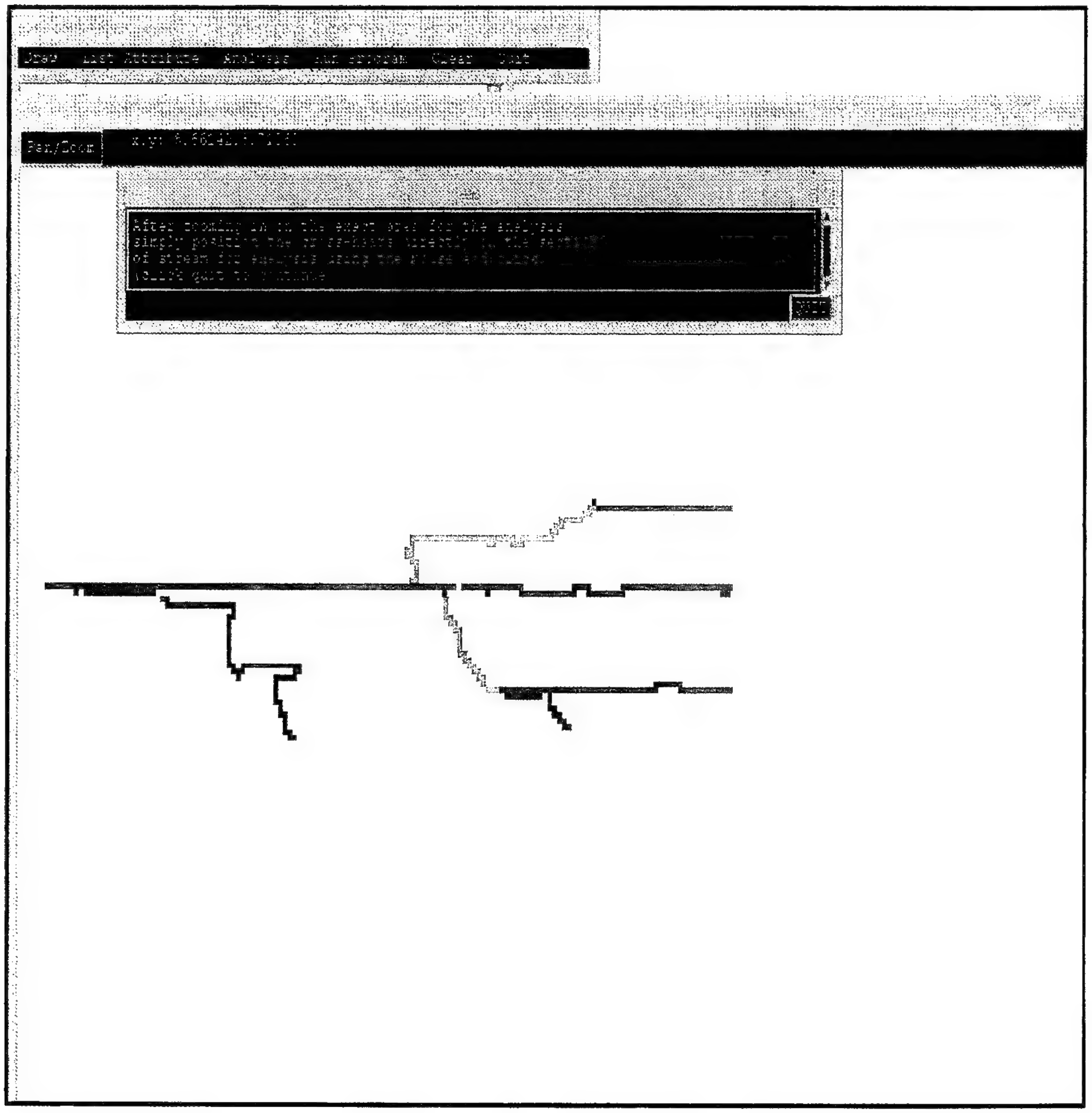


Figure 16: Zoomed In Stream Section.

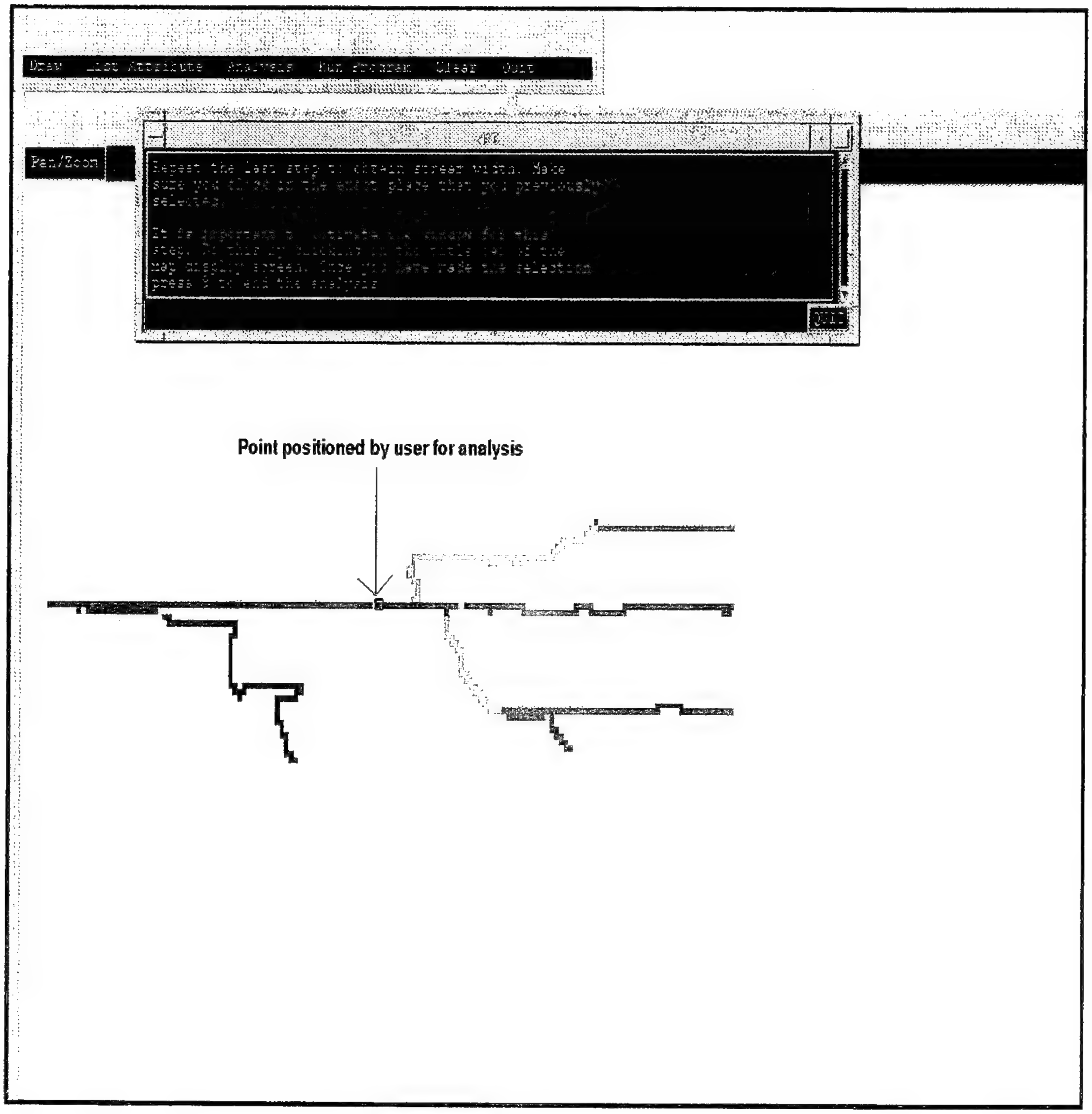


Figure 17: Box Indicating The Analysis Point.

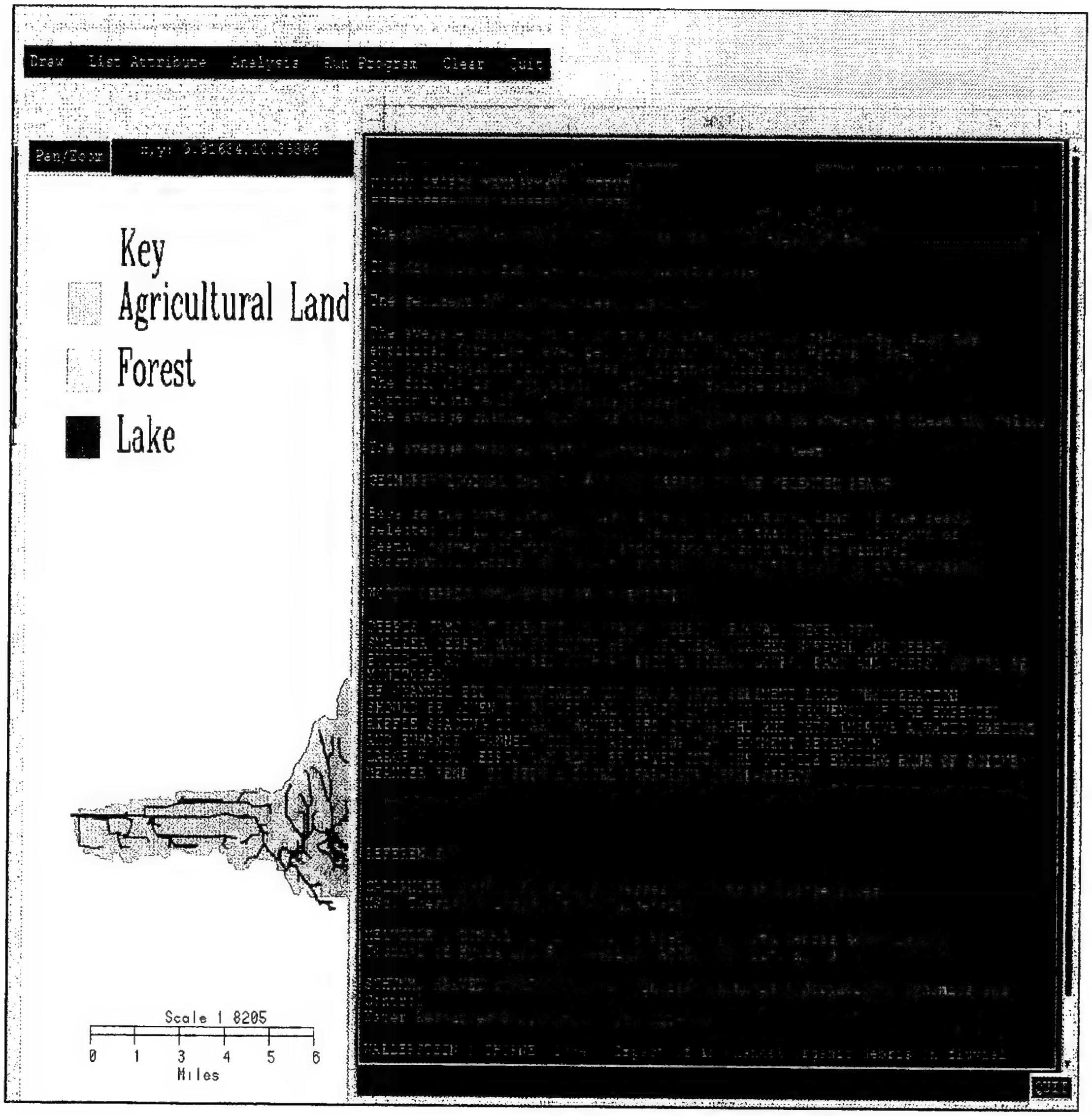


Figure 18: Woody Debris Management Output Display.

arc

```
WOODY DEBRIS MANAGEMENT OUTPUT
------------------------------

The riparian land type in the chosen reach is wooded

The drainage basin area is 2.234 miles square

The default average riparian tree height is 70 feet (based upon field
observaions)

The sediment D50 in this reach is 0.25 mm

The average channel width in the selected reach is calculated using the
empirical formulae developed by Schumm, Harvey and Watson (1984)
for quasi-equilibrium reaches in northern Mississippi.
The formula is : top width = 46.77 * (drainage area)^0.24
bottom width = 15.7 * (drainage area)^0.39
The average channel width has been calculated as an average of these two values

The average channel width in this reach is 39.1 feet

GEOMORPHOLOGICAL IMPACT OF WOODY DEBRIS IN THE SELECTED REACH

Average debris length more than 1.3 times the average channel width.
The main Large Woody Debris (LWD) input mechanism in this reach is tree topple
due
to bank failure in unstable reaches and bank failure in bend apices if the
channel in the reach is meandering. Failed trees are likely to span the channel
at 90
degrees to the flow at the bank-top level creating UNDERFLOW type jams.
(See Wallerstein & Thorne (1994), for a complete description of Deflector type
jams)
Local bed scour may occur under debris at high flows, otherwise the in-channel
geomorphological impact of LWD in this reach will be minimal.

WOODY DEBRIS MANAGEMENT RECOMMENDATIONS

DEBRIS CLEARANCE UNNECESSARY.
SIGNIFICANT LWD IS UNLIKELY TO BE TRANSPORTED DOWNSTREAM FROM THIS REACH, AS
LITTLE
DEBRIS WILL BUILD UP IN THE CHANNEL BELOW THE BANK-TOP LEVEL. BRIDGES AND OTHER
STRUCTURES IN THIS REACH
WILL NOT BE AFFECTED BY PERSISTENT LWD ACCUMULATION


REFERENCES

CALLANDER (1980), Fluvial processes occuring at bridge sites,
MSc. Thesis, Colorado State University.

MELVILLE & DONGOL (1992), Bridge Pier Scour with Debris Accumulation,
Journal of Hydraulic Engineering, ASCE, vol. 118, no. 9
```

QUIT

Figure 19: Further Woody Debris Management Output Display, Indicating Management Action.

4.Discussion.

The data provided by the U.S.Army Corps of Engineers; the soil type, land use, roads, streams and DEM were adequate to carry out the proposed project. Although the stream network was not used because it did not precisely link with the DEM, it was useful as a visual guide, to check the stream network produced by the DEM analysis. The stream network derived from the DEM did not match exactly to the digitally scanned network, although the differences were only slight positional variations and the fact that the derived network appeared more zig-zaggy in shape. These differences did not present a significant problem because the actual stream structure is not used as a significant variable to the program requirements, as long as the different streams were identifiable, which they are. The DEM was perhaps a little coarse in respect of the limiting changes in elevation and because excessive flat spots in some areas caused doubtful stream structure due to discrepancies in the flow direction grid. The stream network shows some stretches of stream that are misleadingly straight; the Southeast section of the streams image, figure 6, is perhaps the best example of this occurring. As Quinn et al (1992) pointed out, the critical catchment characteristic is topography, which has a major control over flow pathways for surface flow. The resolution of the grid in this case has not reflected the features central to the hydrological response, and for this reason a finer resolution scale of 20ft or less would be necessary to lose these inaccuracies in the flow pathway model. The watershed area is in general only slightly undulating, the steepest elevation changes occur in the deep gorges carved out by the streams them selves and therefore a resolution that was less than the average channel width would have provided greater precision, as well as possibly providing better interpretation of the channel structures, such as bank height with

relation to channel width. Such requirements would be very data demanding and time consuming in data gathering, but the eventual results would provide a very constructive and accurate DEM. However for the sake of this analysis the DEM has functioned adequately to demonstrate the workings of this pilot management system. The other data sets provided were accurate in their interpretation of the Abiaca Watershed.

Some mention should be made of the quality of the DEM. Many published DEMs are derived from topographic maps so their accuracy can never be greater than the original source of the data. The most accurate DEMs produced by the USGS. are generated by linear interpolation of digitised contour maps and have a maximum root mean square error of one-half contour interval and an absolute error no greater than two contour intervals in magnitude (Dept. Interior- USGS., 1987). The USGS. DEMs are referenced to true elevations from published maps that include points on contour lines, bench marks, or spot elevations (Dept. Interior- USGS., 1987). However these true elevations can contain errors and it should therefore be appreciated that all DEMs have inherent inaccuracies not only in their ability to represent a surface but also in their constituent data and any results must be looked at with this in mind. The Department of Interior USGS. classify their DEM data into three levels. Level 1, used for this project, is the standard format and has a maximum absolute vertical error of 50 m and a maximum relative error of 21 m. It has been documented by the likes of Carter (1989) that there are inherent errors in DGL format DEM data which include artificial peaks and blocks of terrain extending above the surrounding terrain, particularly along ridge lines. These errors could be due to deficiencies in the interpolation algorithms that produced the DGL data or to an excessive spacing between sampled coordinate pairs along the line data.

Converting the raster data into polygon coverages to carry out the overlay processes was an important feature to generate the attributes for the stream coverage. There is a potential for data processing errors to occur in such processes as raster-to-vector conversions although they are not in general considered highly significant, mainly because the vector representation will mirror the raster coverage. The potential for error is greater when converting vector data to raster because of the fact that the accuracy of point storage in vector data is only limited by floating point accuracy of the computer. Raster data covers the entire study area and the amount of pixels required to maintain the accuracy comparable to that of the vector data would be considerable. This fact results in that through the process of conversion some degree of quantization error must occur. The data which were used for deriving further information was provided in raster format and thus any conversion processes were limited to the less troublesome raster-to-vector method.

The proposed method of overlaying the stream network upon the polygon coverages of soil types and land use to create a stream network which contained these polygon attributes was not the sole method of constructing this form of attribute table. The two polygon coverages could have been overlaid upon each other, using the command UNION, and then the stream network overlaid onto the resulting polygon coverage, the results would have been the same. Another method would have not involved any overlaying techniques at all, but would have made greater use of the RESELECT command. By carrying out the same procedure as the current method the user would select a section of stream for analysis, but instead of the reselect function selecting the attribute related to the stream network it would select the appropriate polygon from which the selected points

coordinates lie from one of the polygon coverages. This procedure would then have to be repeated again to obtain the attributes from the other coverage. Although this method would be quite adequate in obtaining the required results, it was considered inappropriate for the desired application because the chosen method required less user interaction to achieve the same results and therefore was reasoned the better choice.

When using the RESELECT function with the interactive screen selection method ARC/INFO sets an automatic search tolerance which is 1/100 of the current unit distance. This automatic search tolerance made it very simple to select an arc, as the user did not need to be highly accurate in the positioning of the cursor for RESELECT to locate an arc. This situation at first seemingly ideal, but after numerous trails proved to be problematic; if the arc to be selected was near another, a narrow intersection of two streams for example, the reselect function located two arcs and thus selected them both. This was because of the wide search area, so by reducing this search tolerance to a minimal distance, the user although having to be more accurate in the selection procedure would not be chancing the selection of two arcs.

The watershed function operating on the flow direction grid produced from the DEM was reliable in its results, but was heavily dependent on an accurate positioning of the selection point, which the function regards as the outflow point of the sub-catchment for calculation. For this reason it was necessary to zoom in on the stream section for analysis so as to be in a position for greater accuracy in selecting the point. The user is prompted to check the results of this calculation before continuing with running the DMSP, if the calculated area appears inaccurate; for a point positioned near the exit of the total

watershed the area would be expected to be approaching 100 miles square, a slight fluctuation of one or two cells either side of this point can produce results showing as little as 10 miles square, in this case the user would repeat the selection exercise taking greater care with the positioning of the cross hairs. It was found that once the user was aware for the need of accuracy very few mistakes were ever made. The small box displayed on the screen after the RESELECT functions operation served as an extra visual guide for the positioning of the selection point.

The interactive method of selecting the variables for the program was successful in its application, the processing time was reasonably short, the longest calculation taking 55 seconds, the shortest 10 seconds, with a further 20 seconds on top of each for the DMSP processing time. This time is obviously considerably shorter than any manual method that could be carried out.

The pulldown menu system successfully brings the components of the project together under a simple to use interface. The 'Draw' selection gives the user the ability to visually interpret the watershed area, they have the ability to overlay the streams and roads onto either the soils or landuse maps, the overlay of the streams and roads identifies to the user the positions of bridging points. The 'Attributes' selection gives the user an appreciation of the file structure of each data set, as well as allowing them to check what was selected when they ran the analysis section. The 'Analyse stream' selection is perhaps the most important component selection of this menu system. If the user fails to understand how to carry out the selection procedure the system as a 'simple management support system' will have failed. For this reason a series of popup help boxes guide the user through

the process, from instructing how to zoom in on a stream section to indicating how important an accurate positioning of the cursor is to the success of the analysis. The method of displaying the help boxes as ARC/INFO popup boxes causes the operational screen to freeze, therefore the user must quit the popup box before being able to carry on with the analysis. This is a useful feature as it makes the user aware of the help box and does not allow them to make undue hasty mistakes. The 'Run program' selection activates the remaining processes of the project. Once the user has clicked on 'run program' ARC/INFO quits the GRID module and enters TABLES where as detailed in the method an output file containing the three variables is created, the final step activates the TASK function which literally executes the program by passing an on-line command of 3RES (the name of the program) <return>, much in the same way as many programs are activated manually at the keyboard. The output from the DMSP is displayed in a popup box within the ARC/INFO environment. This output file is a normal ASCII text file and can be easily printed off for hardcopy reference.

When activating the menu system from the ARC prompt the first AML sets up the display environment and deletes previously created text files used for the DMSP before accessing the GRID module. It was not possible to delete the INFO file created by the RESELECT within the 'Analysis' section by a simple UNIX command, TABLES had to be activated and then the INFO file called TRY (this is the name of the file created by RESELECT) could be deleted. A simple delete command within TABLES deleted the file TRY, a short AML command carried out this function automatically. This situation was suitable as long as the file TRY existed, if it did not the menu system failed and was deactivated automatically by ARC/INFO.This problem which would always occur when

the program was run for the first time, was overcome by creating a small IF ELSE AML program routine (see appendix A5), basically if.TRY file existed it should be deleted, if it does not exist continue without carrying out the deletion. This process is initiated each time the 'Analysis' routine is run.

The advantages of this pulldown menu system are that for the inexperienced GIS user the ability to carry out various GIS type analyses without any prior knowledge of functionality or basic commands is facilitated. A user can quickly bring up meaningful displays and carry out simple visual overlays. The analysis section requires limited user input and therefore reduces the risk of inaccurate results because of user error. The disadvantages are that such a menu type restricts the user to only the features listed in the menu interface. The user does not have the ability to manipulate any process or carry out other types of analysis. For the more experienced GIS operator such a menu system as this could prove rather frustrating. Building a menu interface based on the FORM menu style of ARC/INFO would be the next step on from this, where the user is directly involved, because the menu type requires much more user input; such as selecting tolerance levels, what features of a coverage to display, colours to be used, and methods of analysis, thus creating a system which is perhaps more flexible, but more complicated to use. The menu system as it is, adequately links the necessary AML routines together, along with activating an outside system program. As a simple one routine management tool it fulfills its requirement , and has formed the potential for further more detailed development. Were it to be used for management assistance as directed it would provide suitable backup for engineers to decide what sort of action should be taken in various areas. The advantage of

such a method is that an engineer can investigate an area of stream(s) before actually visiting the site.

The menu system is structured in such a way that it is easily updated with further AML routines which may carry out additional functions. Attribute tables can be continually added to provide extra information; water quality and peak flow times for streams for example. Additional data layers such as rainfall information, and perhaps more significantly bridge structure data. The roads and stream data layers can be combined to leave the common intersections which can be stored as points which would represent the bridges. Wallerstein and Thorne (1994) are developing a further program which incorporates bridge structure details into its routine. The point attribute tables can be structured so that they would hold information such as platform height, pier spacing and pier diameter. This program determines the land use type up stream from the bridge and calculates the likelihood of debris becoming entrapped in the piers and causing stream bed scour which could result in the failure of the bridge. Obviously to build such a data layer would need considerable field survey inventories of these details from all the bridges in the area, which would be time consuming and costly, but could in time save considerable expense. One of the main limitations of the data layers concerns the land use coverage. The present data separated forest from agriculture which was the first differential the DMSP required. The DMSP has been developed further to take into account the height of the trees. For this project the tree height had been set to an average of 70 ft which was based upon field observations, but if the land use data distinguished between different types of trees and thus tree height, the management support program would provide increasingly refined information. Rather than obtain this land use data from digitised maps, a land use

classification could be obtained with the aid of satellite imagery. The Landsat TM satellite is highly suitable for this purpose, since it has very high resolution in space (30 x 30 m pixels) and 7 spectral bands and satellite data is ideally suited to GIS applications. Other developments to the management program could be considered. An important implication influencing the amount of debris building up at a bridge site or on sharp bends in the streams relate to the sinuosity of the channel up stream from any site. Long straight sections of channel are more likely to hold the potential for transporting floating debris greater distances than meandering sections, more sinuous sections will act as debris traps. Field observations showed that debris jams were more prevalent on the outside of stream bends and extremely rare on straight channel sections. The sinuosity therefore could indicate two implications; at bridge sites with long upstream channel sections which are relatively straight could reveal a greater potential for larger quantities of debris build up, when compared to shorter straight reaches, and sections of streams which are very meandering will trap greater quantities of debris than straighter sections. GIS such as ARC/INFO posses the ability to calculate the sinuosity of a line and therefore some sort of statistical variable relating to this could be investigated towards improvements in the DMSP.

The U.S.Army Corps of Engineers GIS is still in a developing stage where they are continually adding and updating data records, through such schemes as the DEC Project Monitoring Program whose purpose is to evaluate and document watershed response to implemented project features. The purpose of the data collection and data management work is to assemble, to the extent possible, all the data that have been collected to date in the DEC project, and to develop an engineering database/GIS that is

continually updated as new data are collected and analysed. To this date their GIS is not being utilised to its full potential, at present its use is limited to providing information for the hydrologic design of riser pipes and for data visualisation. As the situation develops with the introduction of new data, such as specific design data, the ability of the GIS to contribute further to management strategies such as channel response evaluations, sediment yield reduction studies, and erosion control projects such as this project. It is hoped that the development of GIS applications such as this one will contribute to the engineering activities related to watershed erosion control in the DEC Project.

5.Conclusion

The aim of this project was to develop a simple management support routine through the use of GIS analysis techniques in conjunction with a program which operated outside the GIS environment. It has been shown that a GIS such as ARC/INFO is highly suited to such an application. The reasons for this are; that it incorporates the ability to carry out forms of hydrological modelling and analysis directly suited to this task; it possess the ability to construct and analyses DEMs; it provides a system macro language which enables the various analysis routines to be carried out automatically; it can be developed into a specific project or task orientated menu interface system and it facilitates the ability to execute external programs written in numerous programming languages, such as C++.

A key criteria was to develop the system so that it was simple to use and therefore did not require the operator to have specific GIS training. The system developed shows that this has been achieved through the use of a pulldown type menu system which incorporates help boxes which guide the user through the stream analysis.

As Herndon (1987) has stated there is a need for techniques which will assist with the day-to day practices of land management. Approaches such as this present project are an example of how geographical analysis software such as GIS can be utilised in the management environment, and how it can be appropriate to tailor the operations to specific management requirements, such as erosion control. Management programs can be

developed independently of the GIS and then utilise the analysis techniques of a GIS as a tool in its operation, such as in this case, to find the input variables.

When organisations such as the U.S. Army Corps of Engineers invest large sums of money in to extensive and powerful database/GIS, the development of these systems should provide the ability to improve and create management practices which are proven to be beneficial, not only in their physical results but in their financial savings. This management system has shown that if developed further with the aid of better data and more detailed programming it would provide a valuable tool to the DEC Project and other similar practices.

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Appendix A

ARC/INFO MACRO LANGUAGE PROGRAMS:

1-4 Display AML's

```
1. **land**
clear
mape ab-land-grid         **sets the map extent to the landuse grid file**
map land.map              **displays a map file which has title and key**
map end                   **closes map file**
&return

2. **soil**
clear
mape ab-soil-grid
map soil.map
map end
&return

3. **streams**
mape ab-soil-grid
arcs final-net            **displays arcs coverage**
& return

4. **roads**
mape ab-soil-grid
arcs ab-roads
&return
```

****

```
5. **del.aml**
&if [exists TRY -INFO] &then                 **this is an if - then type statement program
 &do                                            IF an INFO file called TRY exits delete it,
  &sv delstat = [DELETE TRY -INFO]              if not (ELSE) continue and run
analysis.aml**
  &TYPE TRY FILE DELETED
 &end
&else
 &r analysis.aml
 &return
&r analysis
```

6. **file.aml**

```
q
tables                                   **this opens up the module TABLES **
additem test.vat area 14 16 n 3          ** creates new item AREA in the file
test.vat**
select try                               **selectes INFO file try**
unload dump.txt land-code                **creates text file dump.txt inputs
land-code**
select test.vat                          **selects INFO file test.vat **
calculate area = count * 0.00036         **calculates area value**
unload dump.txt area                     **inputs area into dump.txt**
select try                               **selectes INFO file try**
unload dump.txt soil-code                **inputs soil-code into dump.txt**
q stop                                   **quits Tables**
&sv x = [task 3res 'file = 0']           **activates DMSP**
&popup output.txt                        **Displays the output file from the DMSP**
&stop
```

7. **zoom.aml**

```
&POPUP ZOOM-HELP.TXT                     **zooms in on analysis section of streams
mape ab-order                               the * indicates this is a user interaction**
mape *
clear
gridshades ab-order
&RETURN
```

8. **project.aml**

```
&terminal 9999                    **this is the starting AML which sets up the display
rm dump.txt                       environment in ARC/INFO deletes previous text files
rm output.txt                     and then activates the menu file first.menu**
&Fullscreen &Popup
display 9999 3 position ll screen ll
DISPLAY POSITION LR
grid
mape ab-land-grid
&Menu first.menu &PULLDOWN &position &ul &screen &ul &size &frame 700 75
&STRIPE 'Stream Erosion Management System'
```

9. **analysis.aml**

```
&POPUP ANALYSIS.TXT
CLEARSELECT
SEARCHTOLERANCE 150
RESELECT FINAL-NET ARCS ONE *
INFOFILE FINAL-NET ARCS TRY SOIL-CODE TYPE LAND-CODE LAND-TYPE
LIST TRY
&POPUP SHED.TXT
KILL TEST ALL
TEST = WATERSHED (ab-net-flow,SELECTPOINT(ab-elevation,*))
LIST TEST.VAT
&POPUP CHECK.TXT
clearselect
clear
MAPE ab-order
SEARCHTOLERANCE AUTOMATIC
&RETURN
```

Appendix B

The Debris Management Support Program. (author N.Wallerstein)

```
#include <iostream.h>
#include <math.h>
#include <fstream.h>
#include <iomanip.h>
#include <stdio.h>

/* average tree height is seventy feet*/

double drain, sed, result, wid, height = 70.0;
char *rip;
int land;

int main ()
{
ifstream debin("dump.txt");
if (!debin)
        { cout <<"cannot open file";
        }

debin >>land;
debin >>drain;
debin >>sed;

debin.close();

/*average of top width function and bottom width function from schumm, harvey and watson*/

wid = ((pow (drain, 0.24) * 46.77) + (pow (drain, 0.39) * 15.7))/2.0;

if (land == 1)
{rip = "agricultural";}
if (land == 14)
{rip = "wooded";}
if (land == 19)
{rip = "open water";}

ofstream debout("output.txt", ios::app);
if (!debout)
        {cout <<"cannot open file";
        }

debout <<"\n\nWOODY DEBRIS MANAGEMENT OUTPUT\n";
debout    <<"==============================\n\n";
debout <<"The riparian land type in the chosen reach is "<<rip<<"\n\n";
debout <<"The drainage basin area is "<<setprecision(4)<<drain<<" miles square\n\n";
if (land == 14)
{debout <<"The default average riparian tree height is 70 feet (based upon field observaions)\n\n";}
debout <<"The sediment D50 in this reach is "<<setprecision(4)<<sed<<" mm\n\n";
debout <<"The average channel width in the selected reach is calculated using the\n";
debout <<"empirical formulae developed by Schumm, Harvey and Watson (1984)\n";
debout <<"for quasi-equilibrium reaches in northern Mississippi.\n";
debout <<"The formula is : top width = 46.77 * (drainage area)^0.24\n";
```

```
debout <<"bottom width = 15.7 * (drainage area)^0.39\n";
debout << "The average channel width has been calculated as an average of these two values\n\n";
debout <<"The average channel width in this reach is "<<setprecision(4)<<wid<<" feet\n\n";
debout <<"GEOMORPHOLOGICAL IMPACT OF WOODY DEBRIS IN THE SELECTED REACH\n\n";

if ((land == 1) || (land == 19))
{

  debout<< "Because the immediate riparian zone is agricultural land, or the reach\n";
  debout<< "selected is in open water woody debris input through tree blowdown or\n";
  debout<< "death, beaver activity and channel bank erosion will be minimal\n";
  debout          << "Substantial debris jams are therefore unlikely to build up in the reach\n\n";
  debout          << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n";
  debout          << "DEBRIS JAMS NOT PRESENT IN REACH, DEBRIS REMOVAL
UNECESSARY.\n";
  debout          << "SMALLER DEBRIS MAY BE INPUT FROM UPSTREAM REACHES HOWEVER
AND DEBRIS\n";
 debout          << "BUILD-UP AT STRUCTURED SUCH AS BRIDGE PIERS, LOCKS, DAMS AND
WIERS, SHOULD BE MONITORED.\n";
  debout          << "IF CHANNEL BED IS UNSTABLE AND HAS A SAND SEDIMENT LOAD
CONSIDERATION\n";
  debout          << "SHOULD BE GIVEN TO ARTIFICIAL DEBRIS INPUT ON THE FEQUENCY OF
THE EXPECTED\n";
  debout          << "RIFFLE SPACING TO VARY CHANNEL BED TOPOGRAPHY AND THUS
IMPROVE AQUATIC HABITAT\n";
  debout          << "AND ENHANCE CHANNEL STABILISATION THROUGH SEDIMENT
RETENTION\n";
  debout          << "LARGE WOODY DEBRIS CAN ALSO BE KEYED INTO THE OUTSIDE
ERODING BANK OF ACTIVE\n";
  debout          << "MEANDER BENDS TO REDUCE LOCAL NEAR-BANK SHEAR-STRESS\n\n\n";

                }

if ((land == 14) &&( height <= (0.95 * wid)) && ( height >= (0.6 *wid))
&& (sed < 2.0))
                {debout<< "Average debris length lies between 0.95 and 0.6 times channel width.\n";
        debout    << "The main Large Woody Debris input mechanism in this reach is tree topple due\n";
        debout    << "to bank failure in unstable reaches and bank failure in bend apices if the\n";
        debout    << "channel in the reach is meandering. Failed trees are therefore likely to rest in the
channel at 90\n";
        debout    << "degrees to the flow, causing significant local energy dissipation and flow deflection\n";
        debout    << "DEFLECTOR type debris jams are therefore likely to be present in the reach.\n";
        debout    << "(See Wallerstein & Thorne (1994), for a complete description of Deflector type
jams)\n";
        debout    << "The geomorphological impact of this type of jam is erosion of one or both banks\n";
        debout    << "due to flow deflection. This localised bank erosion causes failure, and the input\n";
        debout    << "of new LWD into the affected reach, causing the jam to build up further.\n";
        debout    << "Local bed scour is likely under the debris accumulation because the main\n";
        debout    << "bed sediment type in this reach is SAND. Backwater sediment wedges are unlikely to
form.\n";
        debout    << "upstream of the jam, because the debris jam is too coarse a sieve to hold the sand
bedload.\n\n";
        debout    << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n";
        debout    << "DEBRIS JAM CLEARANCE NECESSARY WHERE LOCALISED BANK
EROSION AND BED SCOUR IS\n";
        debout    << "UNDESIRABLE. BRIDGES SHOULD BE MONITORED ESPECIALLY
CLOSELY FOR JAM BUILD-UP AGAINST PIERS\n";
        debout    << "AS THIS WILL CAUSE EXCESSIVE BED SCOUR, AND FLOW DEFLECTION
AGAINST THE BANK MAY EVENTUALLY\n";
```

```
        debout   << "UNDERMINE THE DECK STRUCTURE. DEBRIS BUILD-UP WILL ALSO
PRODUCE AN INCREASED PRESSURE FORCE\n";
        debout   << "AGAINST THE PIERS.\n";
        debout   << "(See Melville & Dongol (1992) for a method of calculating pier scour due to debris
build-up\n";
        debout   << "and Callandar (1980) for a probability based method of predictng debris build-up at
bridge\n";
        debout   << "piers, and formula for calculating the increased pressure force and flow afflux due to
debris)\n";
        debout   << "DEBRIS SHOULD BE LEFT IN PLACE IF HABITAT ENHANCEMENT IS
DESIRABLE AS DEBRIS WILL PRODUCE\n";
        debout   << "POOLS AND SHALLOWS AND PROVIDE AN ABUnDANT NUTRIENT
SUPPLY, OFFERING A MORE DIVERSE CHANNEL\n";
        debout   << "HABITAT THAN DEBRIS-FREE SAND-BED REACHES\n";
            }
if ((land == 14) && ( height <= (0.95 * wid)) && ( height >= (0.6 *wid))
&& (sed >= 2.0))
            {debout<< "Average debris length lies between 0.9 and 0.3 times channel width.\n"
        << "The main Large Woody Debris input mechanism in this reach is tree topple due\n"
        << "to bank failure in unstable reaches and bank failure in bend apices if the\n"
        << "channel in the reach is meandering. Failed trees are likely to rest in the channel at 90\n"
        << "degrees to the flow, causing significant local energy dissipation and flow deflection\n"
        << "DEFLECTOR type jams are therefore likely to be present in the reach.\n"
        << "(See Wallerstein & Thorne (1994), for a complete description of Deflector type jams)\n"
        << "The geomorphological impact of this type of jam is erosion of one or both banks due to
flow\n"
        << "deflection. This localised bank erosion causes failure, and the input\n"
        << "of new LWD into the afected reach, causing the jam to build up further.\n"
        << "Because the channel sediment D50 type is GRAVEL, jam induced bed scour\n"
        << "will be negligible. Backwater sediment wedges and bars will form, both\n"
        << "upstream amd downstream of the debris jams because of the creation of\n"
        << "a low energy backwater pool and because the debris sieve is fine enough\n"
        << "to retain the gravel bedload.\n"
        << "This process will reduce the rate of sediment routing downstream and help\n"
        << "to reduce bank destabilisation through over-deepening in degrading reaches.\n\n"
        << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n"
        << "DEBRIS CLEARANCE UNNECESSARY, EXCEPT WHERE LOCALISED BANK
EROSION IS\n"
        << "UNDESIRABLE.\n"
        << "BRIDGES SHOULD BE MONITORED FOR JAM BUILD-UP AGAINST PIERS\n"
        << "AS THIS MAY CAUSE EXCESSIVE BED SCOUR, AND FLOW DEFLECTION
AGAINST THE BANK MAY EVENTUALLY\n"
        << "UNDERMINE THE DECK STRUCTURE. DEBRIS BUILD-UP WILL ALSO PRODUCE
AN INCREASED PRESSURE FORCE\n"
        << "AGAINST THE PIERS.\n"
        << "(See Melville & Dongol (1992) for a method of calculating pier scour due to debris
build-up\n"
        << "and Callandar (1980) for a probability based method of predictng debris build-up at bridge\n"
        << "piers, and formula for calculating the increased pressure force and flow afflux due to
debris)\n"
        << "DEBRIS SHOULD BE LEFT IN PLACE IF STREAM HABITAT ENHANCEMENT IS
DESIRED\n";
            }
if ((land == 14) && (height >=(wid*1.3)))
        {debout<< "Average debris length more than 1.3 times the average channel width.\n"
        << "The main Large Woody Debris (LWD) input mechanism in this reach is tree topple due\n"
        << "to bank failure in unstable reaches and bank failure in bend apices if the\n"
        << "channel in the reach is meandering. Failed trees are likely to span the channel at 90\n"
        << "degrees to the flow at the bank-top level creating UNDERFLOW type jams.\n"
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                << "(See Wallerstein & Thorne (1994), for a complete description of Deflector type jams)\n"
                << "Local bed scour may occur under debris at high flows, otherwise the in-channel\n"
                << "geomorphological impact of LWD in this reach will be minimal.\n\n"
                << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n"
                << "DEBRIS CLEARANCE UNNECESSARY. \n"
                << "SIGNIFICANT LWD IS UNLIKELY TO BE TRANSPORTED DOWNSTREAM FROM
THIS REACH, AS LITTLE\n"
                << "DEBRIS WILL BUILD UP IN THE CHANNEL BELOW THE BANK-TOP LEVEL.
BRIDGES AND OTHER STRUCTURES IN THIS REACH\n"
                << "WILL NOT BE AFFECTED BY PERSISTENT LWD ACCUMULATION\n";
                }

if((land == 14)&&(height > (0.95*wid)) && (height<=(wid*1.3))&&(sed >=2.0))
{ debout << "Average debris length is greater than 0.95 times the channel width and\n"
        << "and less than 1.3 times the channel width\n"
        << "The main Large Woody Debris (LWD) input mechanism in this reach is tree topple due\n"
        << "to bank failure in unstable reaches and bank failure in bend apices if the\n"
        << "channel in the reach is meandering. Failed trees are likely to fall into the channel at 90\n"
        << "degrees to the flow completely spanning the channel cross-section, resulting in the\n"
        << "formation of DAM type jams.\n"
        << "(See Wallerstein & Thorne (1994), for a complete description of DAM type jams)\n"
        << "This type of jam will cause significant local bank erosion and bed scour, due to\n"
        << "flow constriction."
        << "Because the channel sediment D50 is GRAVEL, backwater sediment wedges and bars\n"
        << "will form, both upstream amd downstream of the debris jams because of the creation of\n"
        << "a low energy backwater pool and because the debris ""sieve"" is fine enough\n"
        << "to retain the gravel bedload.\n\n"
        << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n"
        << "DEBRIS CLEARANCE MAY BE NECESSARY IF LOCALISED BED AND BANK SCOUR
IS UNDESIRABLE\n"
        << "COHERENT DAM TYPE JAMS MAY ALSO LOCALLY INCREASE THE HEIGHT AND
DURATION OF OVERBANK\n"
        << "FLOODING DUE TO FLOW BACKWATER  EFFECTS\n"
        << "A LIMITED AMOUNT OF DEBRIS MAY BE TRANSPORTED DOWNSTREAM FROM
THIS REACH, AS LITTLE\n"
        << "DAM TYPE JAMS FORM QUITE STABLE STRUCTURES. BRIDGES AND OTHER
STRUCTURES IN THIS REACH\n"
        << "WILL NOT BE AFFECTED BY PERSISTENT LWD ACCUMULATION, ALTHOUGH
SUDDEN DEBRIS PULSES\n"
        << "MAY ARRIVE AT STRUCTURES WHEN DEBRIS DAMS FAIL IN HIGH FLOW
CONDITIONS\n";
}

if ((land == 14)&&(height > (0.95*wid)) && (height <(wid*1.3))&&(sed < 2.0))
{ debout << "Average debris length is greater than 0.95 times the channel width and\n"
        << "and less than 1.3 times the channel width\n"
        << "The main Large Woody Debris (LWD) input mechanism in this reach is tree topple due\n"
        << "to bank failure in unstable reaches and tree topple due to bank failure in bend apices if the\n"
        << "channel in the reach is meandering. Failed trees are likely to fall into the channel at 90\n"
        << "degrees to the flow completely spanning the channel cross-section, resulting in the\n"
        << "formation of DAM type jams.\n"
        << "(See Wallerstein & Thorne (1994), for a complete description of DAM type jams)\n"
        << "This type of jam will cause significant local bank erosion and bed scour, due to\n"
        << "flow constriction."
        << "Because the channel sediment D50 is SAND, backwater sediment wedges and bars\n"
        << "are unlikely form, because the debris sieve is too coarse to retain the sand bedload.\n\n"
        << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n"
        << "DEBRIS CLEARANCE MAY BE NECESSARY IF LOCALISED BED AND BANK SCOUR
IS UNDESIRABLE\n"
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        << "COHERENT DAM TYPE JAMS MAY ALSO LOCALLY INCREASE THE HEIGHT AND
DURATION OF OVERBANK\n"
        << "FLOODING DUE TO FLOW BACKWATER  EFFECTS\n"
        << "A LIMITED AMOUNT OF DEBRIS MAY BE TRANSPORTED DOWNSTREAM FROM
THIS REACH, AS\n"
        << "DAM TYPE JAMS FORM QUITE STABLE STRUCTURES. BRIDGES AND OTHER
STRUCTURES IN THIS REACH\n"
        << "WILL NOT BE AFFECTED BY PERSISTENT LWD ACCUMULATION, ALTHOUGH
SUDDEN DEBRIS ""PULSES""\n"
        << "MAY ARRIVE AT STRUCTURES WHEN DEBRIS DAMS FAIL IN HIGH FLOW
CONDITIONS\n";
}



if ((land == 14) && ( height < (0.6 * wid)))
                {debout<< "Average debris length is less tham 0.6 times the channel width.\n"
            << "Large Woody Debris (LWD) input mechanisms to this reach will include\n"
            << "floatation of debris from upstream reaches, tree toppple due to bank failure\n"
            << "in unstable reaches, and also due to bank failure in bend apices if the\n"
            << "channel in this reach is meandering. Although failed trees are likely to enter\n"
            << "the channel at 90 degrees to the channel, flows will be competant enough to rotate\n"
            << "debris so that FLOW PARALLEL LWD debris jams form. LWD will also be transported\n"
            << "downstream is high flows, and deposited against the bank-base on the outside of\n"
            << "meander bends or at bridge piers and other run-of-the-river structures.\n"
            << "(See Wallerstein & Thorne (1994), for a complete description of FLOW-PARALLEL type
jams)\n"
            << "The negative geomorphological impact of this type of jam in terms of bank\n"
            << "erosion and bed scour is minimal.Bank toes may even be stabilised by debris build-up\n"
            << "Debris may also initiate or acelerate the formation of mid-channel and lateral bars.\n\n"
            << "WOODY DEBRIS MANAGEMENT RECOMMENDATIONS\n\n"
            << "DEBRIS CLEARANCE UNNECESSARY IF IT IS KEYED INTO PLACE AT BANK
TOES OR IN BARS.\n"
            << "BRIDGES AND OTHER RUN-OT-THE-RIVER STRUCTURES SHOULD BE
MONITORED FOR JAM BUILD-UP\n"
            << "(See Melville & Dongol (1992) for a method of calculating pier scour due to debris
build-up\n"
            << "and Callandar (1980) for a probability based method of predictng debris build-up at bridge\n"
            << "piers, and formula for calculating the increased pressure force and flow afflux due to
debris)\n"
            << "FLOATING DEBRIS MAY ALSO PROVE TO BE A DANGER TO SMALL BOATS\n";
                }

debout << "\n\nREFERENCES\n\n"
    << "CALLANDER (1980), Fluvial processes occuring at bridge sites,\n"
    << "MSc. Thesis, Colorado State University.\n\n"
    << "MELVILLE & DONGOL (1992), Bridge Pier Scour with Debris Accumulation,\n"
    << "Journal of Hydraulic Engineering, ASCE, vol. 118, no. 9\n\n"
    << "SCHUMM, HARVEY & WATSON (1984), Incised Channels : Morphology, Dynamics and
Control,\n"
    << "Water Resources Publication, pp. 111-159\n\n"
    << "WALLERSTEIN & THORNE (1994), Impact of in-channel organic debris on fluvial process\n"
    << "and channel morphology, Yazoo Basin, Mississippi, University of Nottingham, Department\n"
    << "of Geography, working paper no. 29\n";
debout.close();


return 0;
}
```